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BY

W. K. Simpson

ELECTROMAGNETIC EFFECTS FROM ATOMIC EXPLOSION

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WT-537 dated January 1953.
Operation Snapper Project 7.1a; Electromagnetic
Effects From Atomic Explosions.

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for *Andith Garrett*
JOSEPHINE B. WOOD
Chief, Technical Support

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WT-537

This document consists of 59 pages

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OPERATION SNAPPER

Project 7.1a

ELECTROMAGNETIC EFFECTS FROM ATOMIC EXPLOSIONS

REPORT TO THE TEST DIRECTOR

by

M. H. Oleson

January 1953

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Headquarters, U. S. Air Force
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AFOAT-1

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ABSTRACT

Studies of electromagnetic pulses emitted from atomic explosions were made at the Nevada Proving Grounds, Stanford University, Boulder, Colorado, Alamogordo, New Mexico, Sterling, Virginia, Maynard, Massachusetts, Robins, Georgia, MacDill, Florida, Bermuda, Puerto Rico, and Germany. With the exception of the close-in station, the experiments were made entirely with standard radio equipment, and standard recording apparatus. Frequencies monitored extended to the maximum usable communications frequency. Measurements of potential gradients and air conductivity were also made within the test area.

The close-in pulse measurements resulted in zero times to ± 0.002 ms, and an approximate estimate of field strengths. The potential gradient and air conductivity experiments showed a definite alteration in the normal current density due to the bomb-caused ionization.

All distant stations reported reception from at least one detonation, except Alamogordo, where extremely low frequencies were monitored, and Maynard, Mass. and Camp King, Germany, where both low and high frequencies were used. No estimates of bomb yield could be made, and pulses received were generally distorted by the equipment used. Obtaining a fix of the bomb explosion with direction-finding equipment appears possible.

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PREFACE

This report presents a summary of AFOAT-1 information on electromagnetic effects from the atomic explosions of Operation TUMBLER-SNAPPER. The basic experimental data were obtained and analyzed by the following groups:

Central Radio Propagation Laboratory
National Bureau of Standards
Washington, D. C.

Air Force Cambridge Research Center
Cambridge, Massachusetts.

Air Weather Service of the Military Air Transport Service
Andrews Air Force Base, Maryland.

Geophysical Laboratory
University of California at Los Angeles
Los Angeles, California.

Unfortunately, it is impossible to mention all who have contributed to the 7.1a project, but credit is especially due the respective project officers of the above groups: Mr. A. Glenn Jean of the National Bureau of Standards; Mr. Lawrence Mansur of the Air Force Cambridge Research Center (Maj. E. H. Nowak of AFOAT-1 made the close-in measurements and assisted with the analysis); Major Clayton Jensen of the Air Weather Service; and Dr. Robert Holzer of the Geophysical Laboratory. In addition, Dr. Clyde Cowan and Mr. J. Howard Parsons of J-Division, Los Alamos Scientific Laboratory contributed suggestions to the project and made arrangements for the close-in experimental work. Major M. A. Hormats of AFOAT-1 and Major H. D. Hutchinson of the Signal Corps were responsible for setting up and operating the "Lamplight" alert system; without this, the operation would have been much more difficult.

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1.0 OBJECTIVE

The 7.1a SNAPPER project was carried out to learn more about the feasibility of using electromagnetic effects from atomic explosions as an adjunct to the AFOAT-1 long-range detection system. This general objective breaks down into more specific endeavors to gain information on: the detection range to be expected, the possibilities of correlating signal characteristics with bomb characteristics, optimum desirable frequencies, changes of signal character with distance, determination of location and types of instrumentation best suited for the above purposes.

2.0 BACKGROUND AND THEORY

2.1 CROSSROADS (Bikini, Summer 1946)

During this operation a rather extensive program was instituted to measure possible direct or indirect electromagnetic effects at the time or shortly after the time of an atomic explosion. As indicated in the summary report of the Technical Director for CROSSROADS ✓, the work was divided into three general problems:

- (1) "the attenuation resulting from propagation through the cloud";
- (2) "the radar reflective properties of the cloud"; (3) "the atmosphere's electrical disturbances developed by the explosion."

There were a number of receiving and transmitting frequencies (from .55 to 23,800 mc). The results were disappointing; briefly, under each heading above,

- (1) "Short range (less than 50 miles) electromagnetic propagation suffered attenuation only if the line of propagation was directly through the cloud." ✓

- (2) Weak X-band radar returns were observed from the airburst.

- (3) Atmospheric noise was reported on only one receiver, set at a maximum sensitivity at 11.4 mc, located about 16 miles from the airburst. "Random noise was observed beginning about 5.5 seconds after the blast and lasting some 2 minutes. The intensity during this period ranged from 13 to 18 db above normal background." ✓

✓ Report of the Technical Director, Operation CROSSROADS, May 1947, Annex G, titled, "Summary Report on Electromagnetic Propagation," by Dr. E. W. Thatcher.



2.2 SANDSTONE (Eniwetok, Spring 1948)

The Air Materiel Command made preparations for measuring possible ionospheric perturbations due to the explosions with a National Bureau of Standards' vertical incidence ionospheric recorder. During trial runs on Eniwetok Island there appeared to be interference with telemetering between Parry Island and bomb detonation points, so the experiment was cancelled by the Commander, Joint Task Force 7. Arrangements were made to set up the equipment on Kwajalein (about 600 km distant), but those in charge of the experiment stated that the experiment was not worth performing if it could not be done on Eniwetok. Hence, the apparatus was repacked and sent back to the States without being used. ^{2/}

The Naval Ordnance Laboratory furnished three Magnetic Airborne Detectors, two of which were located on Eniwetok Island (about 40 km from detonation point) and one on Kwajalein (about 600 km from Eniwetok). The MAD's had a sensitivity of about 10^{-5} gauss; no anomalies were detected that could not be attributed to planes, vehicles or magnetic noise. ^{3/}

2.3 RANGER (Nevada, Jan-Feb 1951)

As far as is known, there were no formal electromagnetic experiments planned for this series of atomic tests. However, there were further attempts to receive radar returns from the post-blast cloud; only one significant report was received. A Sandia group was located within a few miles of the detonation point for the purpose of measuring transit time; they reported that a Brush recorder accidentally left connected to a long, loose wire out of a window was noted to record a rather violent pulse at zero time. Edgerton, Germeshausen and Grier reported that at Boston, they had noticed anomalous bursts of noise on a Panadapter with ham radio equipment, while monitoring a quiet channel close to one giving good West Coast reception. Three of the RANGER shots exhibited unusual bursts of noise within a few seconds of 3.5 minutes after zero times. The time interval was, and is, difficult to explain.

2.4 GREENHOUSE (Eniwetok, early Summer 1951)

Under Project 8.3B, anomalous effects in the ionosphere timed approximately with the arrival of the shock wave and continuing

^{2/}Inclosure O to Tab C, Report of FITZWILLIAM Forward, Report of Operation FITZWILLIAM, Vol. I.

^{3/}Inclosure M, Ibid.

[REDACTED]

for several minutes were noted. 4/ Measurements were made from Parry Island, Eniwetok Atoll. The equipment used was the National Bureau of Standards C-3 Ionospheric Recorder, apparently the same equipment which could not be used during SANDSTONE because of interference with telemetering. A Los Alamos group located on Eniwetok reported that they had noted large electromagnetic pulses from George shot at zero time on 'scopes; the signals had very fast rise times and exhibited exponential decay.

2.5 BUSTER-JANGLE (Nevada, Fall 1951)

During the previous few years, there had been intermittent speculation by several groups on the possibility of atomic bomb electromagnetic effects. Calculations as to the existence and, if so, the characteristics of the electromagnetic field generated varied considerably, depending on the assumptions made. By the time of the BUSTER-JANGLE operation, there seemed to be enough experimental evidence to arouse the curiosity of several groups. Measurements were made, usually with equipment hastily collected and hooked up. There follows a list of the various groups which performed experiments to measure electromagnetic effects:

2.5.1 Los Alamos Scientific Laboratory.

A close-in station (about 12 km from target areas) was operated under the 10.0 Program. This station was primarily for the purpose of obtaining diagnostic information. Various types of antennas were used; receiving equipment was usually broad band, and recording was by means of Brush recorders and photographed oscilloscopes. Various shaped pulses were recorded. At Los Alamos (860 km) reception was effected, by a member of the staff of J-Division, using two one-meter loops at right angles, broad-band receiving equipment, and a Brush recorder. In addition to the first pulse, there also appeared to be secondary pulses. Using a rhombic antenna, 2 mc-14 mc filter, a standard amplifier and oscilloscope, a member of the staff of P-Division has reported that he received pulses at zero times at Los Alamos.

2.5.2 Sandia Laboratory.

While thermal measurements were being made from the station located on Yucca Flat, signals or variation in signals were

4/Project 8.3B GREENHOUSE: Part II, "Effects of Atomic Detonations on Radio Propagation," by Leland H. Stanford, Col. Signal Corps, of Scientific Director's Report Annex 8.3, "Special Radar, Radio and Photographic Studies of Weapons Effects."

[REDACTED]

noted which were apparently due to an electromagnetic effect. In the course of another experiment, primarily for measuring transit time and using a whip antenna, crystal, and amplifier, a damped oscillation was observed at zero time; there was apparently no correlation between amplitude and yield.

2.5.3 Beatty, Nevada.

At Beatty, Nevada, approximately 80 km distant, an apparent drop in the noise level of very short duration at the time of two explosions was noted by using a long wire antenna, amplifier, and tape recorder. Anomalous ionospheric effects were also recorded by means of a C-3 Ionospheric Recorder. ^{5/}

2.5.4 Indian Springs Air Force Base.

AFOAT-1 used standard communications equipment, and enlisted the cooperation of the Signal Corps Engineering Laboratories and the Central Radio Propagation Laboratory of the National Bureau of Standards. At Indian Springs Air Force Base (50 km distant) sharp pulses were detected at zero time and also secondary pulses. Detections were also performed there with electronic counter-measure equipment, and an untuned diode detector. Outputs were recorded on magnetic tape. The Central Radio Propagation Laboratory notified its field stations at Sterling, Virginia (3420 km), Canal Zone (4750 km), Maui, T. H. (4200 km), Anchorage, Alaska (3500 km), and Stanford University (350 km). It appears that only Sterling, Virginia recorded pulses that could be attributed to an atomic explosion.

Results of the BUSTER-JANGLE experiments were not positive for all shots at all locations. In some cases, notifications were not received in time (this is especially true of the distant stations). Timing, as often as possible, was tied to WWV, but, even so, time correlations were sometimes off by tenths of a second. Except where references are listed, the summary of previous results has been obtained in informal meetings and conversations with members of the agencies named; most of the later experimental results have not appeared in formal reports.

2.6 Theory.

The cause of the immediately observed electromagnetic effects is not well known. So far, the data do not present a coherent story. There does not appear to be much question, however, that the

^{5/}BUSTER Project 6.9, "Effects of Atomic Detonations on Radio Propagation," by Col. Leland H. Stanford.

[REDACTED]

rise time of the pulse is very rapid, probably less than 3 or 4 μ s, and that it starts with the emission of the prompt gamma rays, before the case is shattered. After the first few μ s, the picture is more confused, for then the fireball appears, the shock wave proceeds outward, and the ionized column of air is formed. The shaping of the pulse or pulses during this time of several μ s after the emission of the prompt gammas is probably determined by the action and interaction of these effects, modified by meteorological and terrain conditions. Another effect has been postulated, which should also be apparent several μ s after the initial pulse; this is caused by the formation of a conducting sphere in the earth's electric field. The consequent discharge or "shorting" should produce a measurable pulse at comparatively large distances.

3.0 INSTRUMENTATION

Because of the limited time to prepare for the experiment, instrumentation consisted for the most part of existing standard equipment, or that which could be obtained or constructed within the time limits. Figure 3.1 is an outline map showing locations at which experiments were made.

3.1 Timing and Alert System ("Lamplight").

At the Indian Springs Air Force Base four BC-610 transmitters were set up to provide alert and timing information to stations under this project. The BC-610's have a nominal output of 500 watts and the four frequencies were chosen to give as good coverage as possible. The signals in coded voice and very slowly transmitted Morse code were sent out at regular intervals. Beginning 30 minutes before the predicted shot times, the timing signals from the Control Point furnished by Edgerton, Germeshausen and Grier were put on the air; the carriers were cut off the air at -5 seconds. This alert system was used by other programs in various continental locations; usable signals, although not consistent, were received as far away as Boston, Mass.

3.2 Air Force Cambridge Research Center.

3.2.1 Close-in

The Air Force Cambridge Research Center prepared for use by AFOAT-1 personnel at the close-in site on Yucca Flat, a series of tuned circuits with frequencies rising in powers of 10 from 10 cps to 100 mc, with appropriate antennas and amplifiers. A 9-channel Ampex magnetic tape recorder was used as the main recording instrument; 8 channels were used for recording signals and the 9th

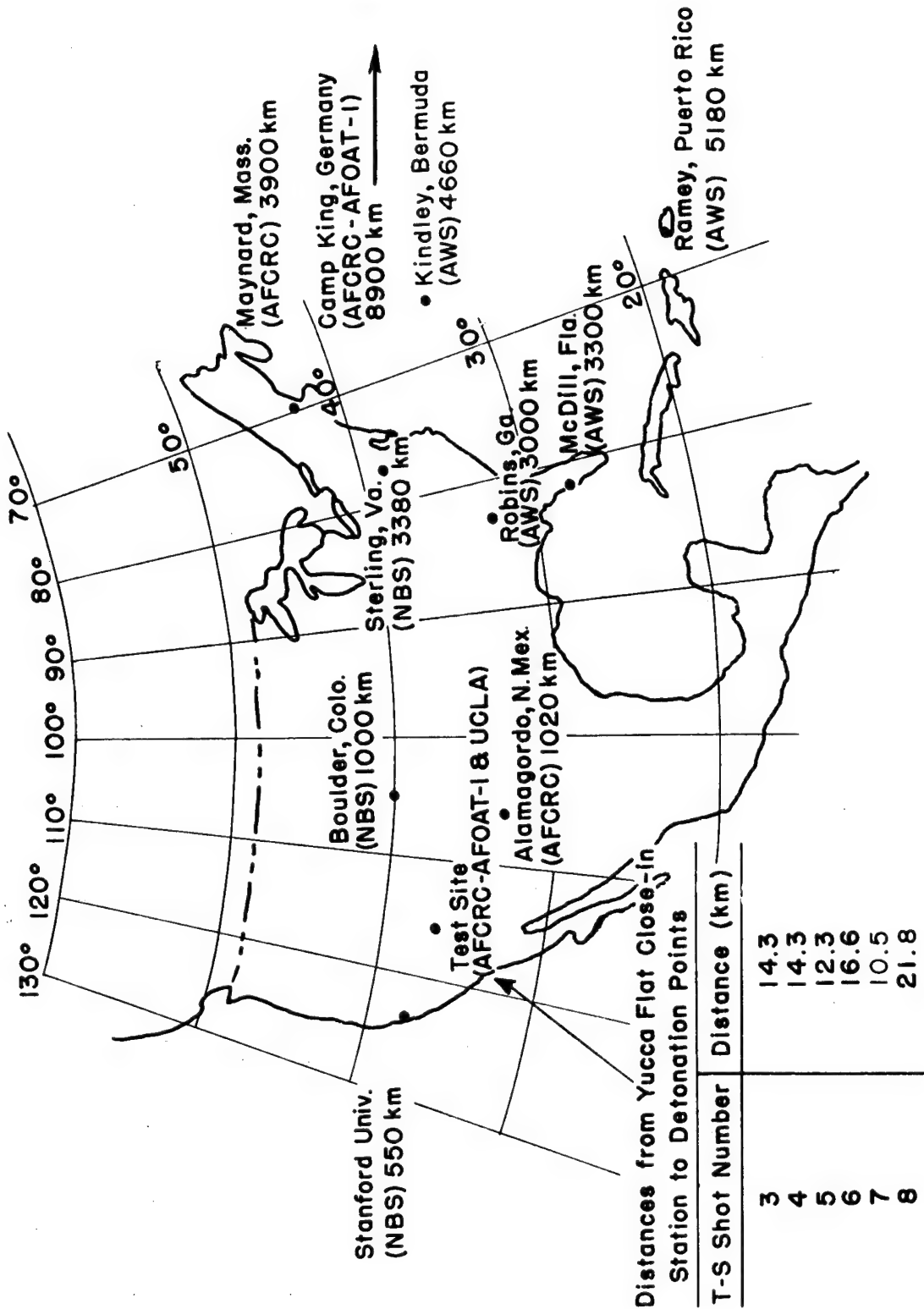


Fig. 3.1 Locations of Electromagnetic Stations, Showing Agencies Performing Experiments, and Distances from Nevada Proving Grounds.

channel was used to record WWV as received on a BC-342 receiver, with a 1000-cycle note superimposed to facilitate time correlation. Two twin-channel Magnecord magnetic tape recorders were also used as a back-up of the untried 9-channel Ampex. One of the twin-channel recorders was used to monitor 10 kc and WWV, and the other 10 mc and WWV. Brush recorders were used on the site to give spot indications of equipment operation. The receiving equipment used is summarized in Table 3.1.

TABLE 3.1

Peak of Frequency Monitored	Antenna Type	Tuned Amplifier Type	Amplifier Gain	Bandwidth (3 db points)
10 cps	Coil, 1 ft in diam, 16,250 turns	Electro-mechanical Research Mod. 35A	6×10^6	1 cps
100 cps	Square loop, 3 meters on a side, 100 turns	AFCRC	600	9 cps
1 kc	ANGRD/1A, 4 ft on a side, 400 turns	AFCRC	750	20 cps
9.3 kc	ANGRD/1A	AFCRC	650	2000 cps
98 kc	150-ft long wire	AFCRC	180	36 kc
0.92 mc	80-meter band whip	AFCRC	200	330 kc
9.16 mc	40-meter band whip	AFCRC	48	1.0 mc
103 mc	Co-ax dipole	AFCRC	3	1.8 mc

All equipment, except a PE-75 motor generator, was housed in a K-53 electronics truck and shipped to the test site in time to participate in Shots 4 through 8. Figure 3.2 is a photograph of the close-in equipment as mounted inside the truck, and Figure 3.3 shows the truck and erected antennas.

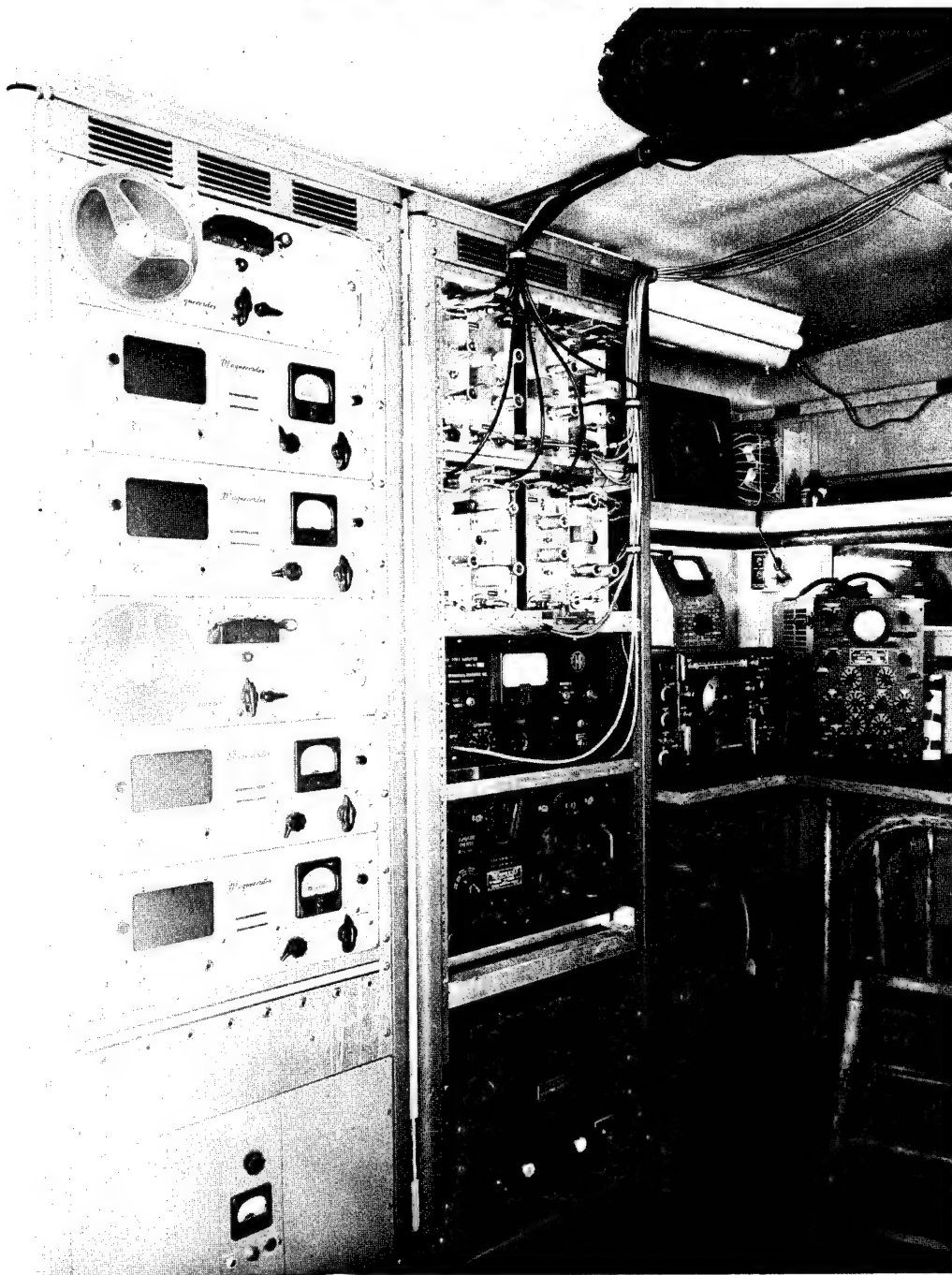


Fig. 3.2 Inside Recording Truck at Yucca Lake Location. Two 2-channel tape recorders and precision 60-cycle source for driving capstan of the 9-channel recorder are in the left rack; from top to bottom in the right rack are two rows of tuned amplifiers, 10 cps E.M.R. amplifier, BC-342 receiver and power supply for the AFCRC amplifier; test equipment is to the right of the picture. The 9-channel tape recorder is located on the opposite side of the truck body.



Fig. 3.3 Instrument Truck at Yucca Lake Location. The power supply is in center of picture. Pieces of weighted foil in foreground were interconnected and used as an experimental ground by Los Alamos Project 16.

[REDACTED]

3.2.2 Maynard, Mass. and Alamogordo, N. Mex. -
Very Low Frequency.

The very low frequency equipment at each location was essentially the same. It consisted of a large coil with about 31,000 turns as the pickup unit, a special very low frequency amplifier (.5 to 20 cps range and 150 db gain) and a custom-built paper and ink recorder. One channel of the recorder was used for WWV timing as picked up on a receiver, and the other was fed by the output of the low frequency amplifier.

3.2.3 Maynard, Mass. - High Frequency.

Standard radio receivers, recorders and antennas were used in various combinations for monitoring a low frequency (usually 50 kc) and a high frequency close to the Maximum Usable Frequency (MUF) (usually between 5 mc and 20 mc). WWV was used for timing. The equipment used follows:

<u>Receivers</u>	<u>Sensitivity</u>
1 National HR060	1 μ v for S/N = 6
2 Hallicrafters SX28	1 μ v for S/N = 5
1 Hallicrafters SX25	1 μ v for S/N = 6
1 Hammarlund Super Pro	1 μ v for S/N = 9
1 Browning Laboratory WWV receiver (fixed tuned for either 5 mc or 10 mc)	

Recorders

- 1 Magnecord dual-channel magnetic tape
- 1 Ampex single-channel, Mod. 400 magnetic tape
- 2 Dual-pen Brush recorders (paper tape)

Antennas

ANGRD/1A, long wires, 3-element 20-meter beam

3.2.4 Camp King, Germany.

The most distant station under this project was at Camp King, Germany. The equipment was constructed and assembled by the Air Force Cambridge Research Center and operated by AFOAT-1 personnel. The equipment is listed as follows:

Low Frequency


- 1 Loop Antenna, 100 turns on 10-ft square form. This antenna is referred to as the CRL antenna.
- 1 Loop Antenna, 400 turns on 1-meter square form (ANGRD/1A). This antenna is referred to as the GRD antenna.
- 2 Variable Rejection Filters, Krohn-Hite model 300A.
High and low cut-off frequencies independently variable from 20 to 200,000 cps.
Attenuation in rejection band 24 db/octave.
Gain unity. Internal generated noise under 5 millivolts (mainly 60 cycle hum).
- 2 Variable Band Pass Filters, Krohn-Hite model 310A.
High and low cut-off frequencies independently variable from 2000 to 200,000 cps.
Attenuation outside band pass 24 db/octave.
Gain in band pass: unity. Internal generated noise 50 μ v.
- 2 Vacuum Tube Voltmeters, Hewlett Packard, model 400C with the following modifications: the feed back loop removed, and all 0.22 μ fd coupling condensers replaced with 0.1 μ fd condensers.
- 2 Dual-channel tape recorders (Magnecord).

High Frequency

- 1 SCR 779 Receiver, sensitivity 1 volt for S/N = 5.
- 1 Magnecord dual-channel tape recorder.

Other

- 1 High-frequency receiver for WWV.
- 1 Hewlett-Packard VTVM Mod. 400C (unmodified).



3.3 Institute of Geophysics of the University of California At Los Angeles.

Under Contract AF 19(122)-254 with the Air Force Cambridge Research Center, the Institute of Geophysics is investigating the behavior of air-earth currents, electric fields, and air conductivity during meteorological disturbances. During the BUSTER tests, measurements had been made at locations between 35 km (20 mi) and 55 km (34 mi) from the detonation points, but there were no observable effects. To further this research, arrangements were made to attach Institute of Geophysics personnel to the 7.1a project for making close-in potential gradient and air conductivity measurements during the TUMBLER-SNAPPER series of tests. As reported by Dr. Holzer: ^{6/}

".....Four instruments were used to measure potential gradient. Two were of the induction type (subsequently called GI and GII) used in conjunction with amplifiers and Esterline-Angus recorders. The advantage of this type of instrument is relatively high time resolution, limited only by the type of recorder used. Two of the potential gradient meters (RI and RII) were of the radioactive collector type in which a polonium strip is attached to a stretched insulated wire parallel to the ground. The potential of the wire in one case was measured by a rugged portable quadrant electrometer designed for field use. In the second radioactive collector instrument, the wire potential was measured by an electrometer circuit and recorded on an Esterline-Angus instrument. The stretched wires were raised to various heights above the ground, from 1 to 8 meters, during calibration and measurement. The latter type of potential gradient meter is more sluggish than the induction type but is useful for absolute measurement of the potential gradient. All of the potential gradient instruments were checked against each other for intervals of several hours and found to give proportional responses.

"The conductivity meters (KI and KII) were modified Gerdien instruments in which the air is drawn between concentric cylinders and the ions collected at the central cylinder. The ion currents were measured by Applied Physics Corporation Model E electrometers and recorded on Esterline-Angus recorders."

The instruments for the experiments were placed as shown in Table 3.2:

^{6/}U. Cal. Inst. of Geoph. Sci. Report No. 4, "Atmospheric Electrical Phenomena in the Vicinity of Nuclear Fission Explosions," by R. Holzer.

TABLE 3.2

DISTRIBUTION OF INSTRUMENTS

Date and Time of Test	Station Location	Distance from Ground Zero	Instruments at Station
April 22 Shot 3	Yucca Lake Frenchman Flat	14.3 km 27.5	GI,RI,KI GII, KII
May 1 Shot 4	Yucca Flat Yucca Lake Frenchman Flat	7.8 14.7 22.7	GII GI,RI,KI RII, KII
June 1 Shot 7	Yucca Lake Yucca Lake	10.2 14.1	GI, KII RII
June 5 Shot 8	Yucca Flat Yucca Flat Yucca Lake	10.0 14.0 21.4	RII GII GI, KI

3.4 Central Radio Propagation Laboratory of the National Bureau of Standards.

3.4.1 Boulder, Colorado.

Narrow band and broad band low frequencies and narrow band high frequencies (close to MUF) were monitored. All low frequency measurements used a single turn loop 200 ft by 60 ft, oriented for maximum signal from the test site. "The size was such that the maximum detectable signal was limited by external noise rather than set noise." ^{1/} A cathode follower was placed between the antenna and a Navy RBA receiver (band width 500 cps) and a sferics type receiver (band width about 180 kc). Pulses were recorded on magnetic tape. For high frequency reception a National NBS-1 receiver was used with a Signal Corps Type A rhombic antenna directed toward the bomb site. In these tests the bandwidth was 10 kc, 6 db down. Magnetic tape was also used for recording the output of the high frequency receiver.

"At Boulder it was necessary to mix a time signal with the desired signal because only single-channel recording equipment

^{1/} NBS Report 3C101, "Remote Detection of Radio-Frequency Radiation Accompanying the Detonation of an Atomic Bomb," by A. Glenn Jean.

[REDACTED]

was available at the time. For Shots 2 and 3 the filtered output from a WWV receiver as well as the Lamplight tone was mixed with the desired signal. Due to the limitations of the WWV timing system (not firing when the WWV carrier was weak and pulsing several times in succession on strong atmospherics), this unit was abandoned after Shot 3. For Shots 4 and 5 only the Lamplight carrier was mixed with the desired signal for fear that the test results would be obscured by extraneous pulses from the WWV timing unit.

"The time interval between the end of the -5 second steady carrier from Lamplight and the desired signal has been determined for Shot 4 as 5.00 seconds and for Shot 5 as 5.039 seconds." 7
The time interval between the end of the 5-second tone and the shot time for Shots 7 and 8 were measured at the close-in station resulting in 5.07 seconds for Shot 7 and 5.01 seconds for Shot 8.

"A Bliley 100-kc secondary frequency standard having a short-term stability of about one part in 10^7 was procured, and a frequency divider was constructed to provide one pulse each second. This unit was completed in time to be used for timing on Shots 6, 7 and 8 at Boulder. This timing unit was synchronized with station WWV once or twice each day....."

3.4.2 Sterling, Virginia.

Narrow band high frequency and low frequency equipment with magnetic tape recorders was used; on the last two shots, auxiliary IF output of the Super-Pro receiver was fed through a separate detector to one channel of a 2-channel oscilloscope; the other channel was used for monitoring WWV. The low frequency antenna was a single turn loop 350 ft by 150 ft oriented east and west; for high frequency reception a rhombic antenna 825 feet long and 213 feet wide oriented toward White Sands, New Mexico was used.

3.4.3 Stanford University.

The Central Radio Propagation Laboratory station at Stanford University performed narrow band high frequency experiments (close to the MUF) with a 35-foot vertical antenna and a Super-Pro receiver; two oscilloscopes with a mirror and camera recorded the received pulses and WWV time ticks. A receiver with a bandpass from 0.5 to 50 kc for listening to atmospheric "tweeks", with an oscilloscope sweep and camera triggered by the received pulses was also used. Vertical incidence ionospheric recordings were made with a standard C-3 recorder beginning 5 minutes before a 5-minute period during which the bomb was exploded, and for 30 minutes thereafter.

3.5 Air Weather Service.

Sferics equipment is used primarily as a weather prediction tool. The equipment, called Static Direction Finder AN/GRD-1A, was developed for the Air Weather Service by the Signal Corps Engineering Laboratories. Areas of thunderstorms are located by triangulation using three or more widely separated stations. At each station records are obtained showing time to about ± 0.05 sec and azimuth for each flash to about $\pm 3^\circ$. Experience has shown that the vicinity of 10 kc produces the best signals; the equipment is narrow band (between 1/2 to 1 kc).

Two loops, each 54 inches on a side, and containing 400 turns of wire, are accurately oriented at right angles to each other, one in a North-South plane and the other in an East-West plane. The output of each loop through identical tuned amplifier circuits is fed to the plates of an oscilloscope. By placing one on the horizontal plates and the other on the vertical plates there appears on the oscilloscope face a line or flash having the "directional and magnitude characteristics of the vector sum of the two induced voltages." ^{8/} A strip film camera, with film moving at about 1 in/sec, records the signals received. Timing is furnished by a synchronous motor (line frequency stabilized by a tuning fork) which drives a commutator causing neon flashes at 1-sec and 0.1-sec intervals which appear as marks on the film edges. The timing is synchronized with WWV at the beginning of each run at each station. Photographic equipment for developing the 35-mm film completes the essential apparatus at each station. Further details on this standard equipment can be obtained from Technical Manuals. ^{9,10/}

4.0 RESULTS AND DISCUSSION

4.1 Close-in

4.1.1 Pulse Measurements

The truck containing equipment for close-in pulse measurements arrived at the Nevada Proving Grounds to participate in Shots 4 through 8. The truck was placed in a fixed position on the dry Yucca Lake bed adjacent to the LASL Program 16 station. The distances from the station to detonation points are given in Figure 3.1.

^{8/} Operation TUMBLER-SNAPPER: "An attempt to Detect and Locate Atomic Detonations at Great Distances, by Clayton E. Jensen, Major, USAF, Air Weather Service.

^{9/} TM 11-2693, "Static Direction Finder AN/GRD-1A"

^{10/} TM 11-2338, "Camera PH-557/TFH, Developer PH-559/TFQ, Viewer PH-558/TFP"

[REDACTED]

4.1.1.1 Recording and Analysis

Tape recordings were made during each shot for a period of 11 minutes before each shot and 6 minutes after. This assured more than one WWV time announcement, background recording before the shot, and recording of possible after-effects. Analysis of the records was performed at the AFCRC by using the following procedure:

(a) The tapes were played back, and earphones used to locate the zero pulse.

(b) The section including zero time was played back through a 6-channel Brush recorder. These paper tapes were used to view the recorded pulses.

(c) For final analysis a dual gun oscilloscope and a Dumont Fairchild camera were used. The signal from each channel in turn was applied on one gun of the oscilloscope and the timing signal on the other. The signals furnished a horizontal deflection, and the motion of the film was used for a time base. Two film speeds were used for each record, one at about one inch per second and the other about 6.5 inches per second.

Figures 4.1 - 4.8 are oscilloscope photos of magnetic tape recordings for all frequencies and shots monitored. For counting time between the WWV pips a 1000 cps oscillator was mixed with the output of the WWV receiver; the 1000 ripple is quite evident in Figure 4.9 in an enlargement of the 10 kc and 1 mc signals from Shot 8. It will be noted in Figures 4.1 - 4.9 that the event signal on the WWV traces comes after the direct recorded trace. The automatic volume control of the WWV receiver was turned on in order to minimize fading. A very strong signal produces a few ms delay under such receiver conditions, and the bomb signal was strong enough to cause such a delay. There was no such delay in the relatively weak WWV signals. The WWV listening frequencies varied, depending on atmospheric conditions, from 5 mc to 15 mc for the various tests.

4.1.1.2 Times of Pulse Reception

Times of reception of the first sharp pulse as determined from the analysis done by the AFCRC are given in Table 4.1.

4.1.1.3 Field Strength

It was hoped that the experiment would result in field strength values. However, this did not eventuate.

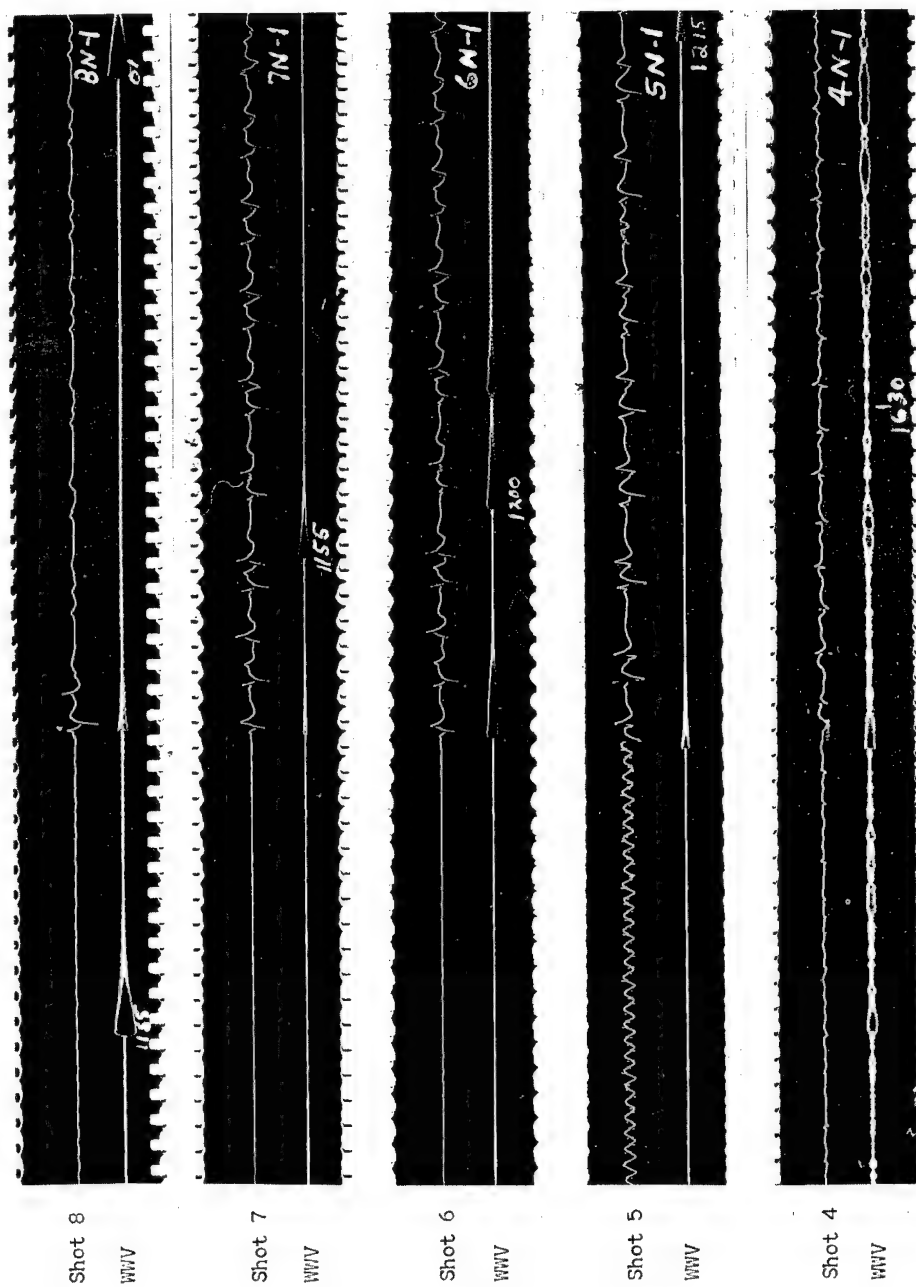


Fig. 4.1 Oscilloscope Record from Magnetic Tape, 10 cps; Shots 4 - 8; Film Speed 6.5 in/sec

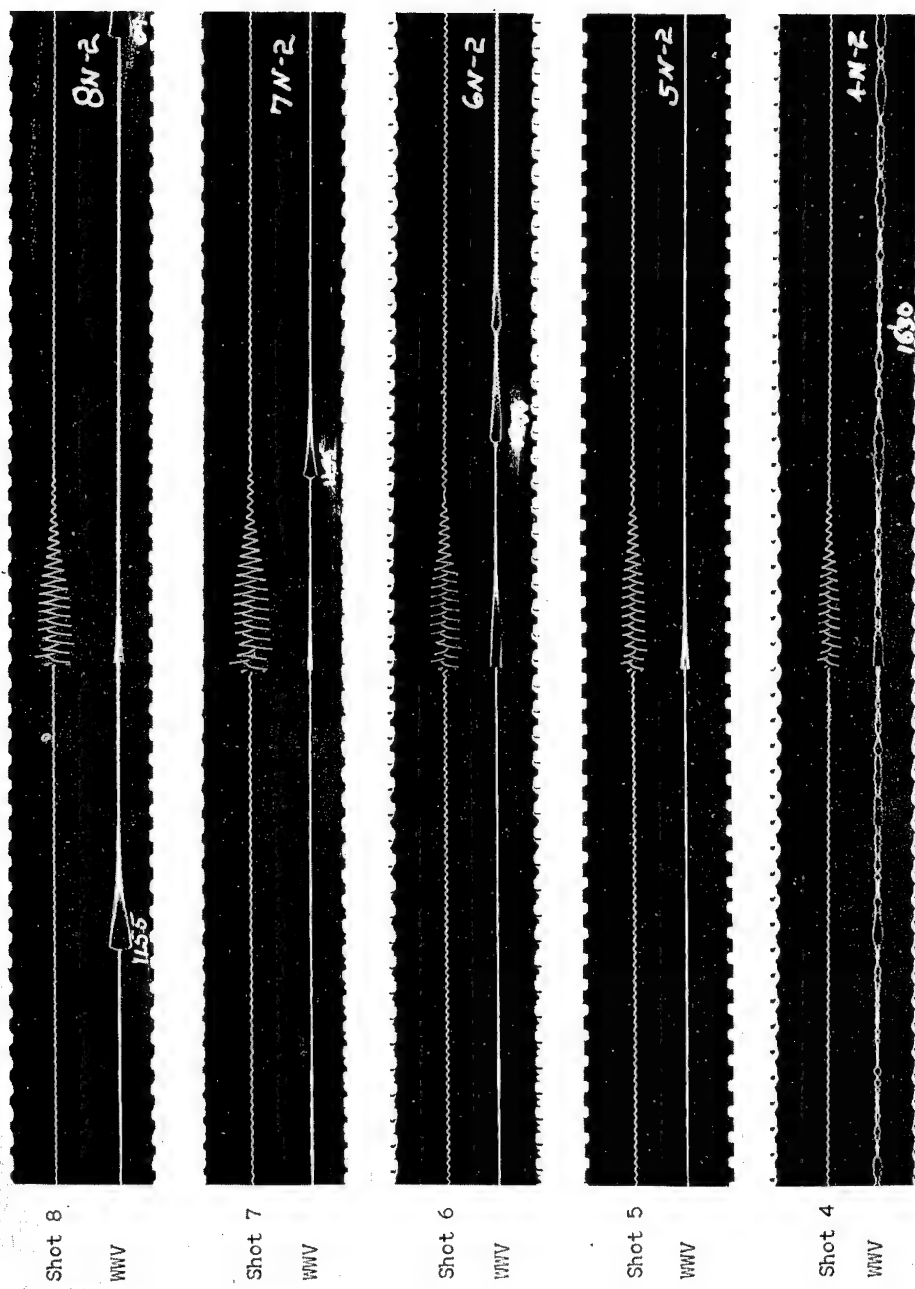


Fig. 4.2 Oscilloscope Record from Magnetic Tape, 100 cps; Shots 4 - 8; Film Speed 6.5 in/sec

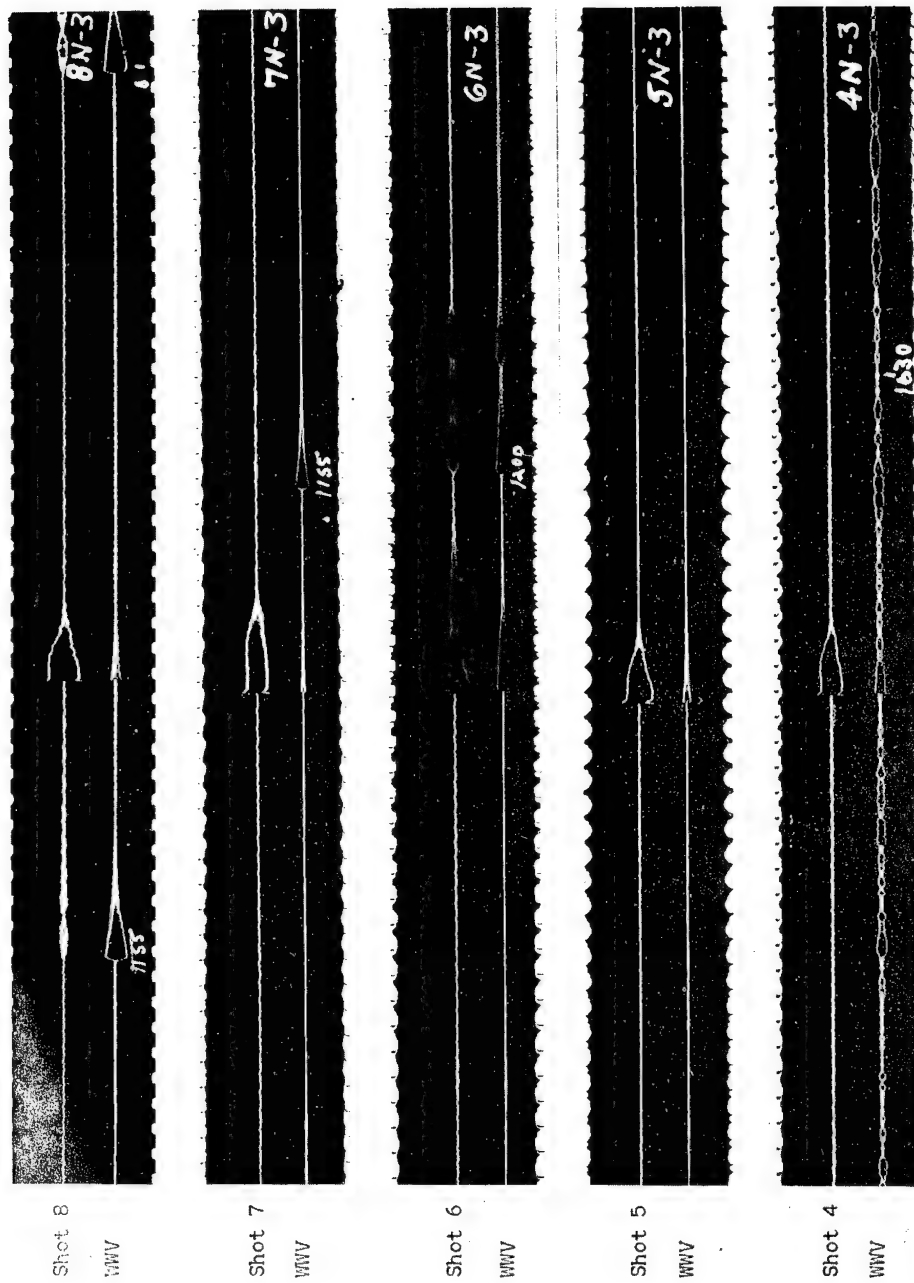


Fig. 4.3 Oscilloscope Records from Magnetic Tape, 1 kc; Shots 4 - 8; Film Speed 6.5 in/sec

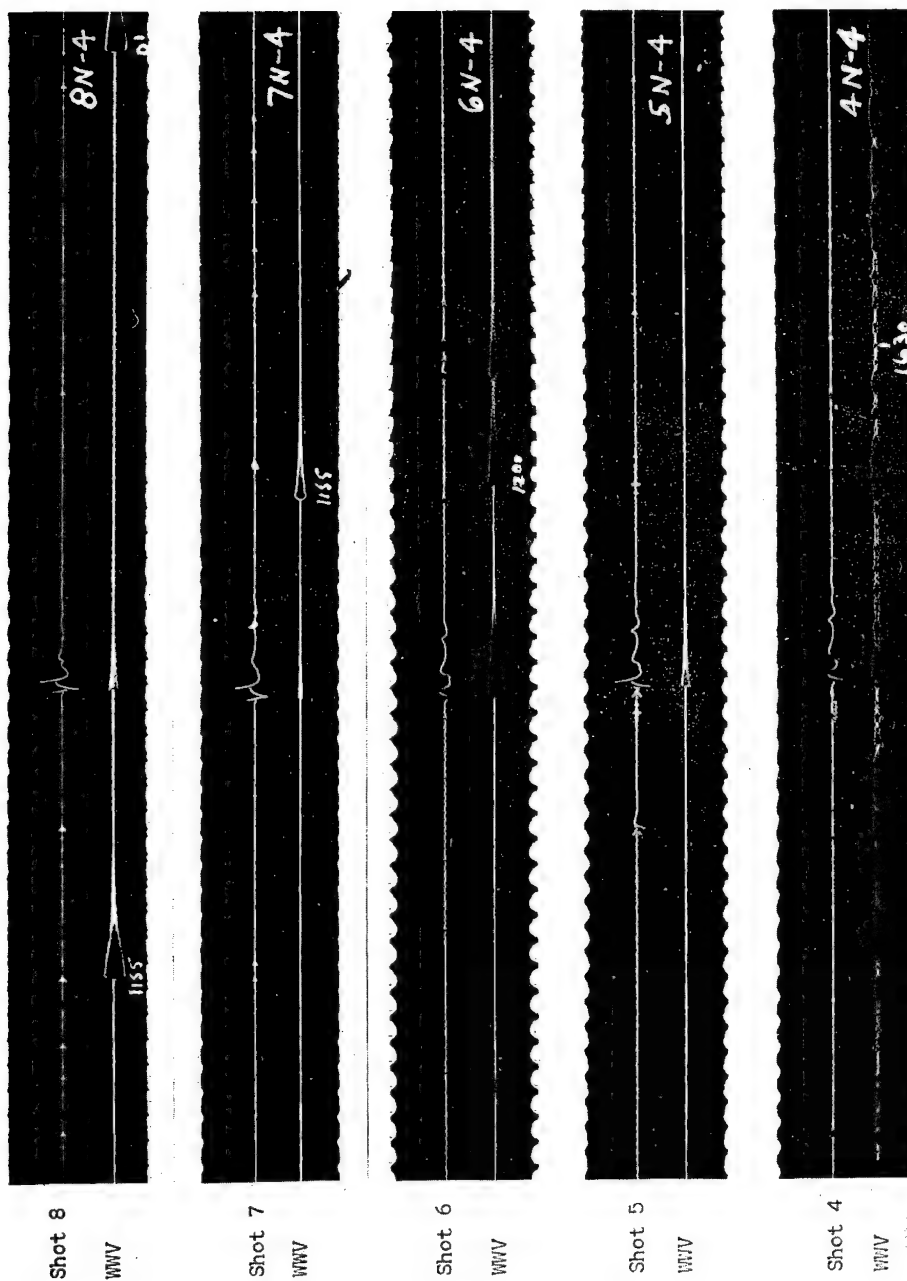


Fig. 4.4 Oscilloscope Records from Magnetic Tape, 10 kc; Shots 4 - 8; Film Speed 6.5 in/sec

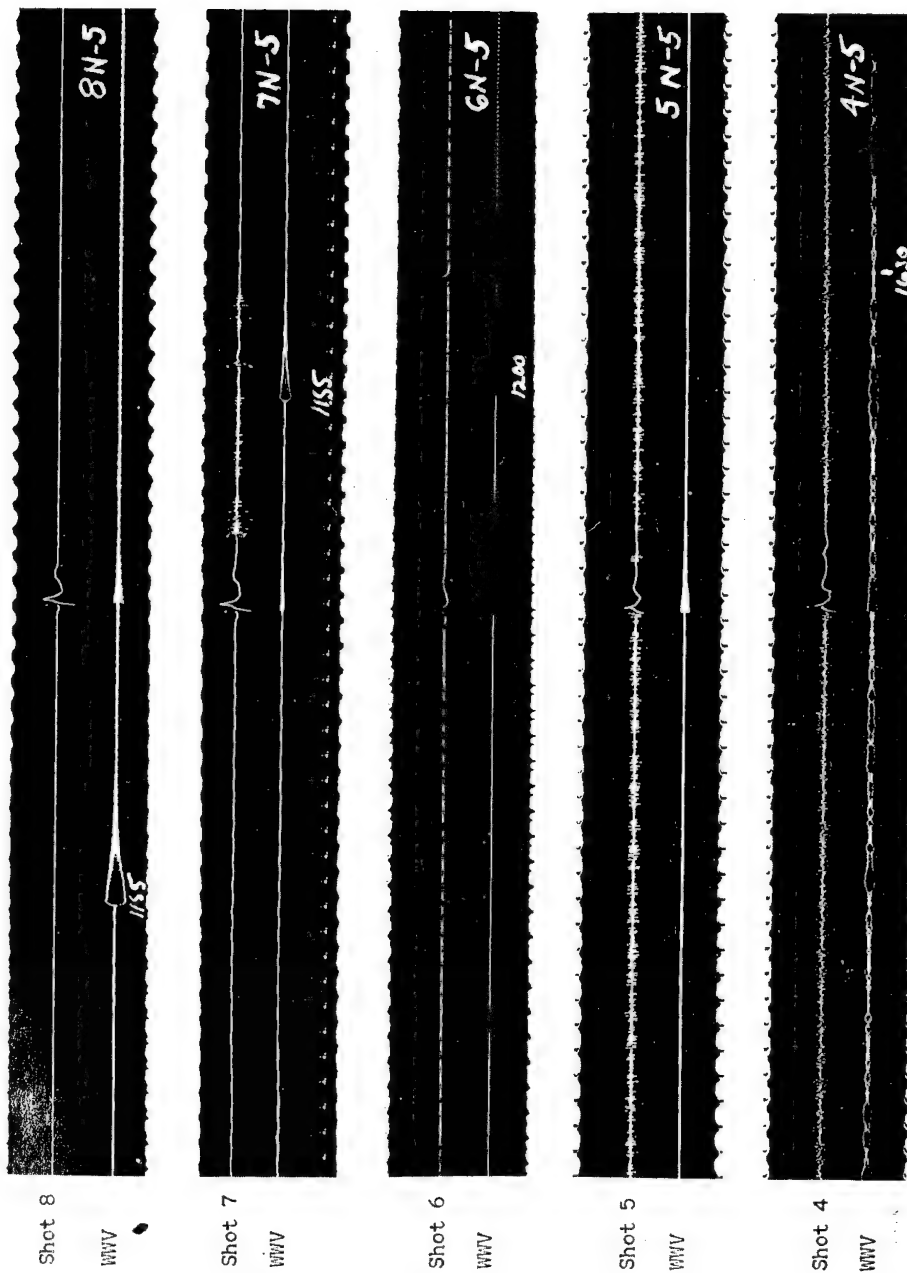


Fig. 4.5 Oscilloscope Record from Magnetic Tape, 100 kc; Shots 4 - 8; Film Speed 6.5 in/sec

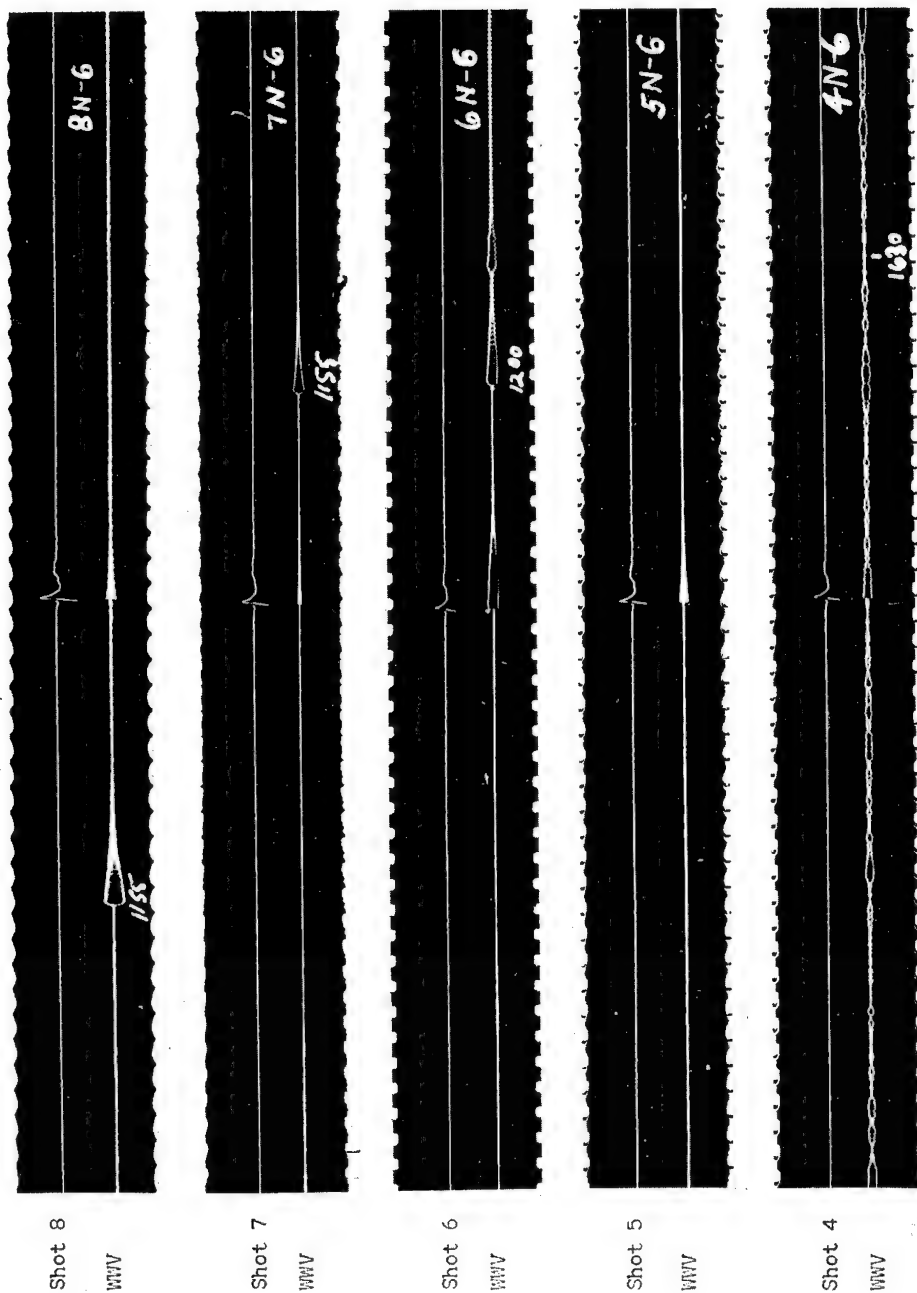


Fig. 4.6 Oscilloscope Record from Magnetic Tape, 1 mc; Shots 4 - 8; Film Speed 6.5 in/sec

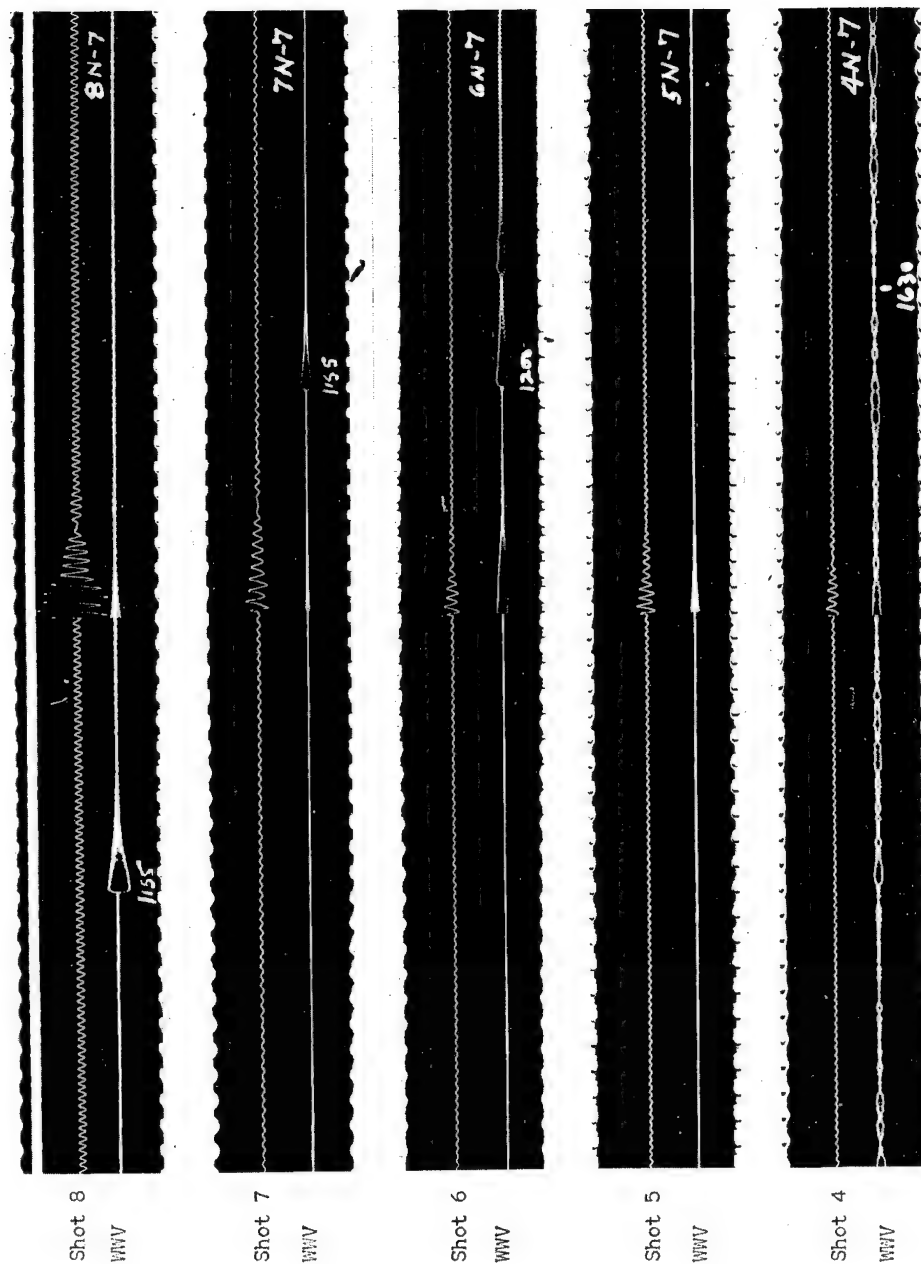


Fig. 4.7 Oscilloscope Record from Magnetic Tape, 10 mc; Shots 4 - 8; Film Speed 6.5 in/sec

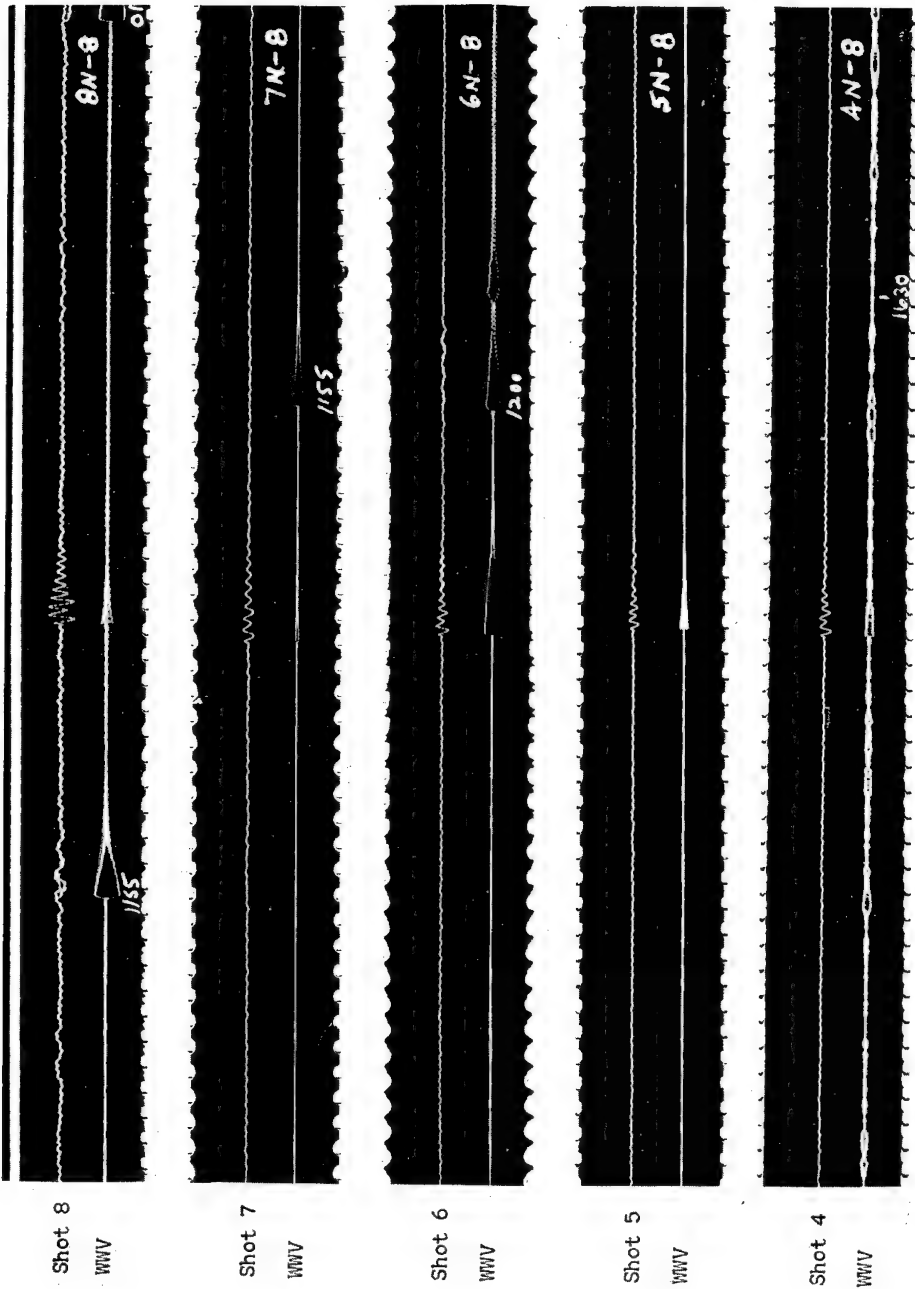


Fig. 4.8 Oscilloscope Record from Magnetic Tape, 100 mc; Shots 4 - 8; Film Speed 6.5 in/sec

10 kc

WWV

1 mc

WWV

Fig. 4.9 Shot 8; 10 kc and 1 mc Signatures with WWV and 1000 cps
Note Impressed

[REDACTED] [REDACTED]

Circuit ringing was obvious on 10 cps, 100 cps, and 1 kc. The wave shape was distorted due to overloading. However, using a signal generator tuned to each respective frequency, it was possible to get an approximation of the signal barely sufficient to overload the Ampex amplifier. It was learned that very similar signals to the double pulses on 10 kc, 100 kc and 1 mc could be produced in the Ampex recorder by feeding a square wave pulse into the amplifier. Various pulses up to 10 μ s in duration and 70 volts amplitude were tried. Only pulses greater than 3 μ s passed through the amplifier, and with these pulse widths it was possible to saturate the Ampex amplifier and simulate rather closely the wave forms shown in Figures 4.1 - 4.8. The position of the second spike was dependent only on the degree of amplifier overloading; pulse width (up to 10 μ s) had no effect on the distance between spikes. Gains of the 10 mc and 100 mc channels were determined by using a pulse modulated signal generator. The signals recorded in these two frequencies were found to have been produced by feed back from the 100 cps amplifiers through the common power supply. With the above limitations in mind, the following approximations were arrived at for Shot No. 8:

<u>Frequency</u>	<u>Approximate Field Intensity</u>
10 cps	300 μ v/m or greater
100 cps	0.4 volts/m or greater
1 kc	2.2 volts/m or greater
10 kc	9.2 volts/m
100 kc	0.02 volts/m
1 mc	.2 volts/m
10 mc	Less than 20 μ v/m
100 mc	Less than 300 μ v/m

The value for 100 kc is surprisingly low, but this was the only channel that used a horizontal antenna. This seems to indicate that the signal was vertically polarized.

4.1.1.4 Other Measurements

The equipment was operated during the high explosive tests on 20 May (2 sets of data) and 1 June (1 set of data). Also, on 20 May, records were made during a dry run to check for possible

[REDACTED]

signals from line or switching transients. On none of the above experiments was there any recognizable signal.

During Shot 4 the 10 cps antenna was in a N-S vertical plane and standing on a large wooden box; for all subsequent tests the antenna was buried in the ground in an E-W vertical plane to minimize pickup by movement in the earth's field. In addition to a signal at zero time, a disturbance beginning at about 4.5 seconds after zero time lasting for about 16 seconds was noted. This signal may have some connection with the seismic shock, but the time of arrival was about 2 seconds later than might be expected. However, limited geologic information indicates that the low velocity sediments increase in thickness toward the southern portion of the valley; this may account for the late arrival. A third disturbance was noted beginning about 38.5 seconds after zero time. This probably was caused by the shock wave; an extrapolation of a Shot 4 time-distance curve ^{11/} gives a time of 39.4 seconds.

4.1.2 Atmospheric Current Density

4.1.2.1 The First 3 Minutes

Measurements were made ".....toward determining changes in the atmospheric conduction current density, the product of potential gradient and conductivity. At all positions where the conductivity was measured there was no significant change in conductivity immediately following the explosion. Because the conductivity near the surface of the earth fluctuates, very small changes of the order of 10 per cent could not have been quantitatively determined. Within this uncertainty, the conduction current density at the observing stations may, therefore, be assumed proportional to the potential gradient. One important exception to this statement undoubtedly occurred at the nearest stations where the shock wave kicked up appreciable amounts of dust. The conductivity was not measured at the nearest stations (see Table 4.1) and the potential gradient changes were considered proportional to the conduction current density only until the shock wave reached the station.

"The pattern of potential gradient changes was substantially similar at all stations where observable changes occurred. At the time of the explosion (time H), there was a sharp decrease followed by a rapid recovery (within a fraction of a second) undoubtedly due to electromagnetic radiation from the explosion. Thereafter the potential gradient again fell rapidly, reaching a minimum at

^{11/} Operation TUMBLER, Projects 1.3 and 1.5, "Free-Air and Ground-Level Pressure Measurements," by C. J. Aronson et al, WT-513.

[REDACTED]

about H plus 2 seconds. The potential gradient remained at its minimum value for intervals from 20 to 60 seconds and then recovered slowly, returning to its normal value about H plus 3.5 minutes.

"At stations approximately 10 kilometers from ground zero the magnitude of the change was greater than the normal value of the gradient, and the gradient reversed sign. At 14 kilometers or more the magnitude of the change was not sufficient to reverse the gradient." 6/

Figure 4.10 shows the variation of the maximum fractional change as a function of distance.

4.1.2.2 Between 3 and 13 Minutes

On Shot 3 (22 April) and Shot 4 (1 May), the potential gradient continued to rise after it had reached its normal value at the Yucca Lake station, and finally leveled off at a value of 30 per cent greater than prior to the explosion. This was not observed on 5 June.

4.1.2.3 Atomic Cloud Effects

On 22 April, a portion of the cloud passed directly over both observing stations. Changes are shown in Figure 4.11. The potential gradient at Yucca Lake started to increase at H plus 25 minutes after the explosion, reached a maximum of about 10 times normal at H plus 45 minutes and then returned to normal at H plus 2 hours. A similar pattern was observed at Frenchman Flat after about 32 minutes time elapse. At H plus 2 to 8 hours, the conductivity at Frenchman Flat began to increase, reaching a value about 6 times normal. The speed of the cloud movement, as calculated from the appearance of peaks at the two locations is 13.5 knots, which agrees well with the mean wind speed of 13 or 14 knots between 10,000 and 25,000 feet.

4.1.2.4 Discussion

An idealized picture of the condition in the vicinity of an atomic explosion a few seconds after the detonation is presented in Figure 4.12. It is indicated ".....that the first burst of ionization increases the atmospheric conductivity by some six orders of magnitude within a kilometer of the explosion. The conductivity approaches normal values between 8 and 10 kilometers along the surface and about 12 kilometers above the explosion. It should be noted that the normal conductivity 12 kilometers above the explosion is more than an order of magnitude larger than the normal surface value. The effects of this rapid change are as follows: (1) Normally vertical

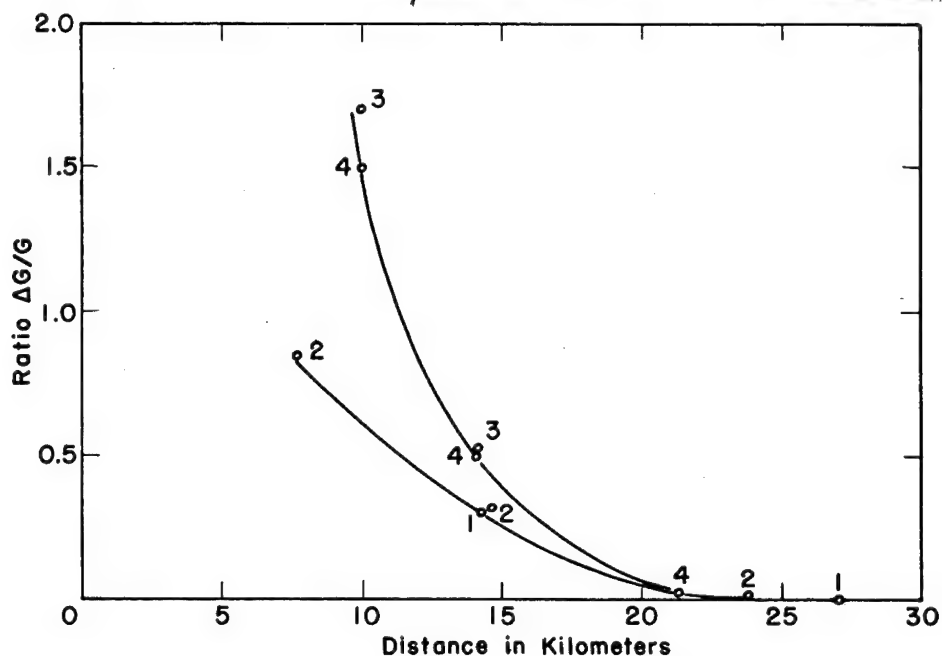


Fig. 4.10 Fractional Change in Potential Gradient as a Function of Distance from Explosion. 1 and 2 are air bursts; 3 and 4 are tower shots. 6/

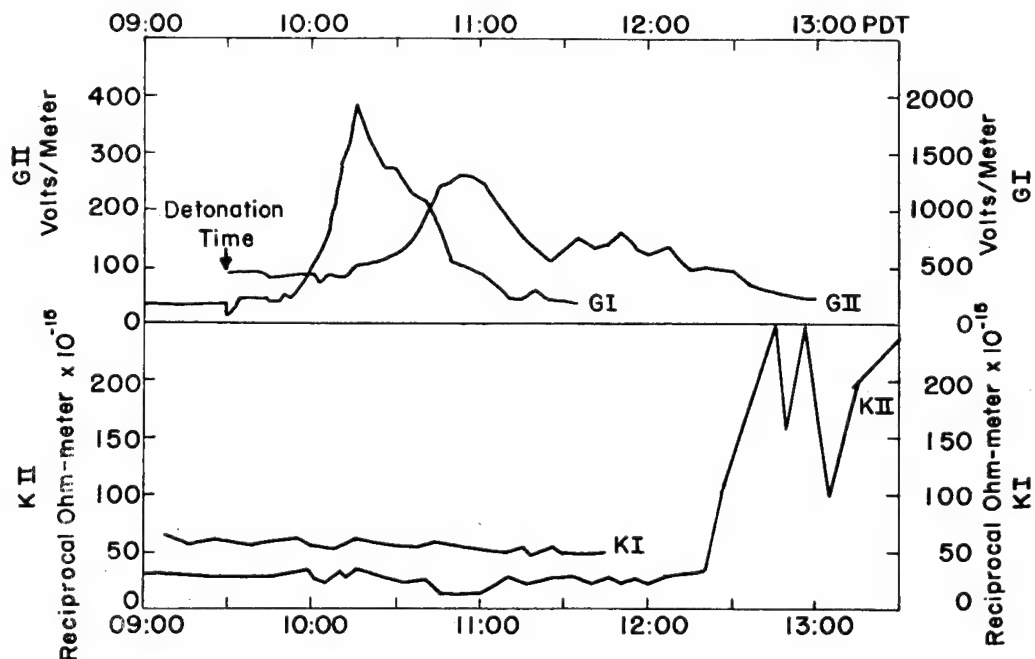


Fig. 4.11 Potential Gradient and Polar Conductivity as Functions of Time. Shot 3, 22 April 1952. GI and KI, Yucca Lake, 14.3 km from Ground Zero; GII and KII, Frenchman Flat, 27.3 km from Ground Zero. 6/

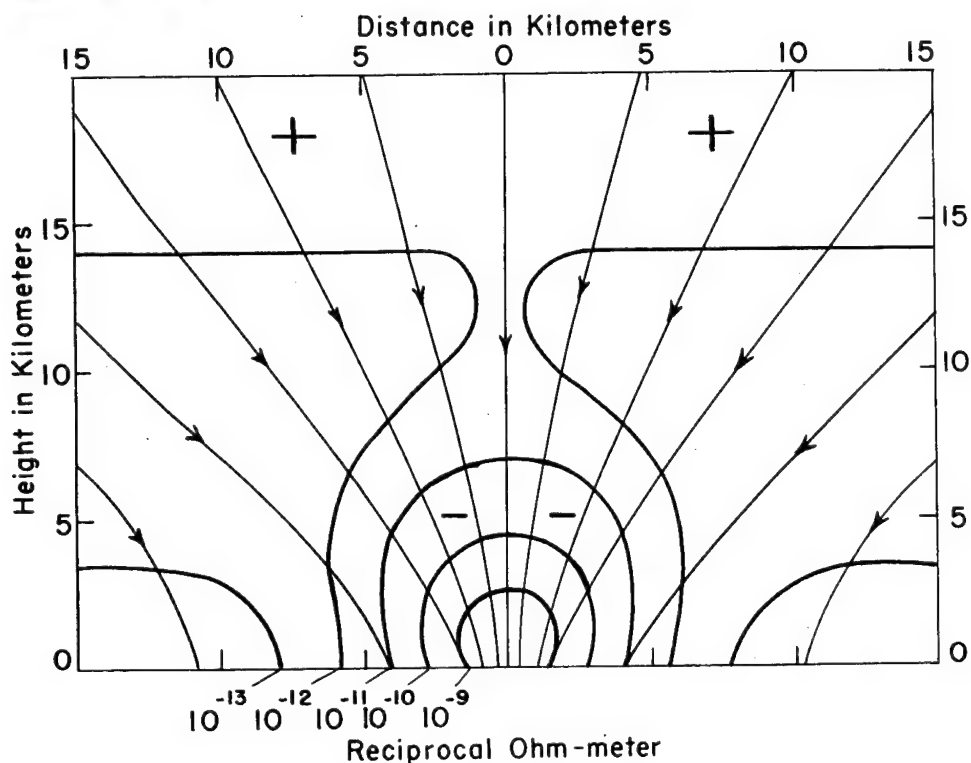


Fig. 4.12 Schematic Diagram Showing Distribution of Conductivity (heavy lines, in $\text{ohm}^{-1} \text{m}^{-1}$) and Current Flow (light lines) in Vicinity of Nuclear Bomb, 10 sec. after Detonation. ^{6/}

current flow lines will converge on the region of the explosion. (2) The equipotential surfaces will become convex upward and in the region above the bomb will closely parallel surfaces of equal conductivity. (3) Current densities in the regions of enhanced conductivity will increase greatly, at a kilometer above the explosion by some three orders of magnitude greater than the normal value. (4) Nearly coincident with the explosion there will be a rapid surge of current toward the earth giving rise to electromagnetic radiation and producing negative space charge in the region where the explosion has created a conductivity gradient. (5) In regions above the explosion where the conductivity and conductivity gradient are normal but where the current density has been increased, positive space charge density will increase above its normal low value. (6) At surface stations, even at distances well beyond the points at which the atmospheric conductivity is changed, the air-earth current density and hence the potential gradient will be diminished due to disturbance of the normal current flow at altitudes of many kilometers over the station." ^{6/}

[REDACTED]

These simplified assumptions do not account for the observed reversals in sign of potential gradient at the surface as close as 10 kilometers from the detonation point. This mechanism could be one of driving negatively-charged particles faster than positively-charged particles. This would be effective if there were an asymmetry, such as proximity to the ground, or possibly, varying meteorological conditions. It is noted in Figure 4.11 that at the nearest station to point zero on 1 May, an air drop 1000 feet above the surface and ~8 kilometers distant showed no reversal while lower shots (~10 kilometers distant) did show reversals.

On 22 April and 1 May it was noted that the potential gradient returned to its original value after 3 or 4 minutes and then increased to about 30 per cent greater than background. This occurrence was associated with the formation of a large dust cloud. Conductivity within the cloud is probably much less than normal, and hence the resistance greater. "Accordingly, the lines of current flow originally converging toward the radioactive cloud which increased the conductivity in the same volume some five minutes earlier, would at this stage diverge tending to reduce the current density in the cloud. The current density would be expected to rise at distances of several kilometers beyond the edge of the cloud.

"No such effect was observed on June 5 when the dust cloud appeared visually to be very much smaller and less dense." 6/

When part of the radioactive cloud passed over the station (Figure 4.11), it is postulated that it acted to concentrate the current flow through the cloud and the area immediately under neath.

The increase in conductivity at the Frenchman Flat station became apparent as soon as radioactive particles from the cloud had fallen to the ground. It is quite certain that these effects would have been detected at Yucca Lake if the recording had continued.

4.2 Distant Sites

4.2.1 Boulder, Colorado (1000 km)

4.2.1.1 Low Frequency Tests

As mentioned before, two types of low frequency equipment were used, a relatively narrow band (~500 cps) Navy type RBA receiver, and a wide-band receiver having essentially

[REDACTED]

constant gain from 200 kc down to band rejection notches at 18 and 15 kc. The output of the narrow band receiver was recorded on magnetic tape and the wide band output as presented on a cathode ray tube was photographed with a 20-in/sec strip film camera. Second marks tied to WWV were recorded by intensity modulating the cathode ray tube, and for time interpolation the X-axis was swept with a triangular voltage wave at a frequency of 60 cps. The RBA narrow band equipment was tuned to clear channels for each shot with the following results:

<u>Shot</u>	<u>Frequency, kc</u>	<u>Remarks</u>
2	55	Spurious time marks mask any signal
3	156	No observable signal
4	18 or 19	Signal observed
5	18 or 19	No observable signal
6	19	Signal observed but high local camera noise level
7	18 or 19	Signal observed
8	19	Signal barely distinguishable in high noise level

The magnetic tapes were played back through a scope and pictures were taken with a Land camera triggered by the pulse. Figures 4.13 and 4.14 show low frequency pulses for Shots 4 and 6 as received on the narrow band equipment. No significant results were obtained with the low frequency broad band equipment.

4.2.1.2 High Frequency Tests

All records were made with an Ampex magnetic tape recorder, which presents a characteristic pulse distortion. The high frequency equipment as used at Boulder did not give a double pulse response to a single steep wave front. The length of received pulses shorter than about 100 μ s are not recorded, although it was experimentally determined "....that single short pulses were not split in any way due to receiver characteristics." 17

An analysis of the received pulses so as to show pulse shape shows double pulses for some shots which can be approximately correlated with reflections from more than one ionospheric

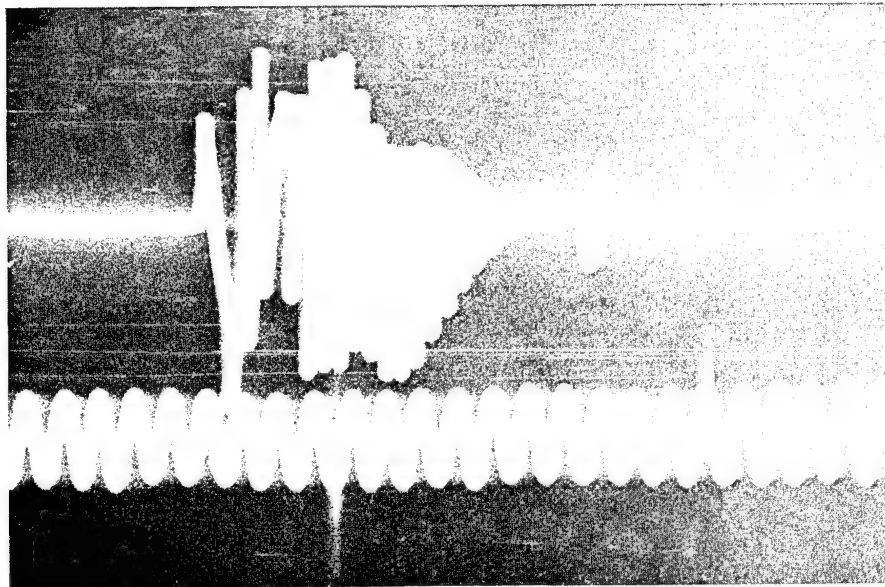


Fig. 4.13 Boulder, Colorado. Typical Low Frequency Pulses as Recorded on Narrow Band Equipment. Shot 4; 18.7 kc. The damped waveform ringing at an approximate frequency of 1300 cps produced in the receiver.

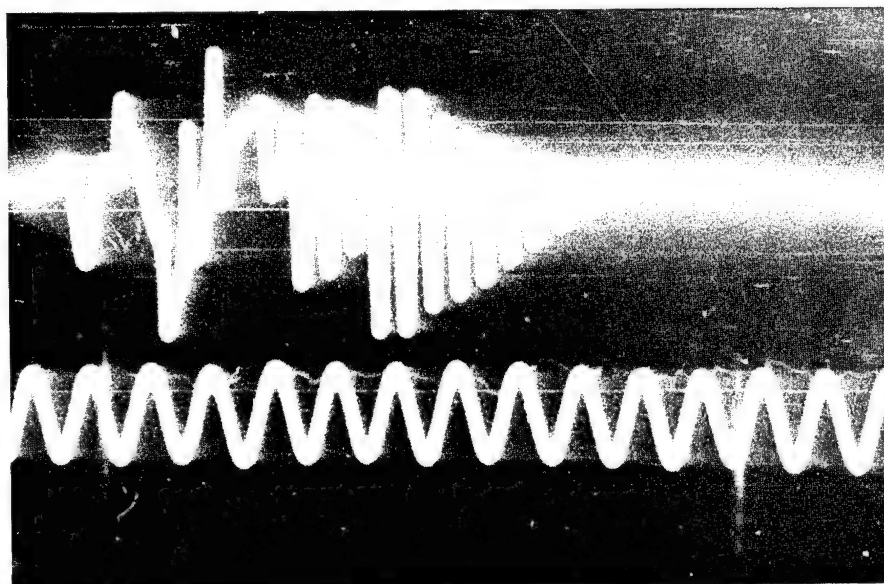


Fig. 4.14 Boulder, Colorado. Typical Low Frequency Pulses as Recorded on Narrow Band Equipment. Shot 6; 19.4 kc.

[REDACTED]

layer. Data from the closest ionospheric recording station at White Sands, New Mexico, were used for calculation purposes. Double pulses were recorded only on days when only F_2 and either F_1 or E layers were present; single pulses were received when E_s was present and presumably blanking out the other layers. Figure 4.15, for Shot 3, 9.10 mc, shows oscilloscope transcriptions from the magnetic tape, the first at a speed to show the entire signal, and the second at a faster speed to show first pulse wave form as recorded on the tape. On this date (22 April) White Sands data indicate:

f_oF_2 of 7.3 mc at 310 km
 f_oF_1 of 4.5 mc at 200 km
 f_oE of 3.1 mc at 105 km

The difference in path length between a reflection from 105 km and 310 km is about 152 km, as compared with the equivalent of 101 km from the record. Figure 4.16 are records of pulses received on Shot 5, 5.06 mc, 7 May, when no double pulses were evident. On this date, White Sands data indicate:

f_oF_2 - 2.6 mc @ 340 km
 f_oF_1 - (distant layer not present)
 f_oE - 1.1 mc at 120 km
 E_s - 2.3 mc at 120 km

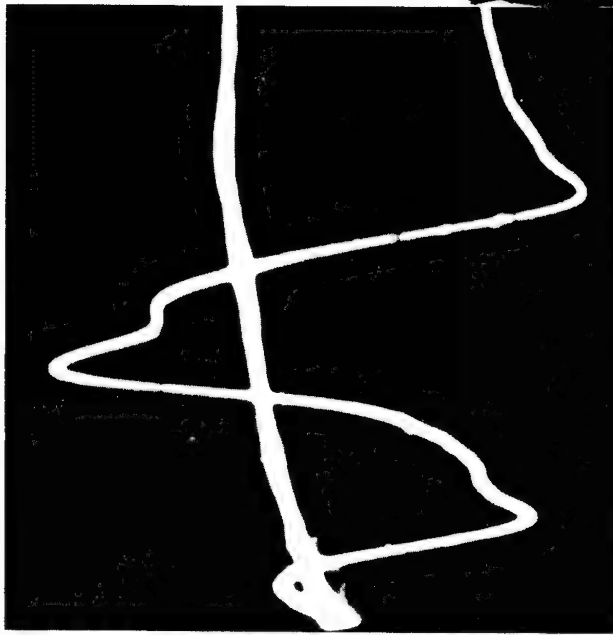
Single pulses were recorded from Shots 4 and 5. Double pulses were recorded from Shots 3, 6 and 7. No records were made of Shots 1 and 2. Zero time determinations are given in Table 4.1.

4.2.2 Stanford University, California (550 km)

Measurements were conducted for Shots 5 through 8. Severe interference from a nearby spark transmitter obscured any signals that might have been received from Shot 5. Pulse measurements were made:

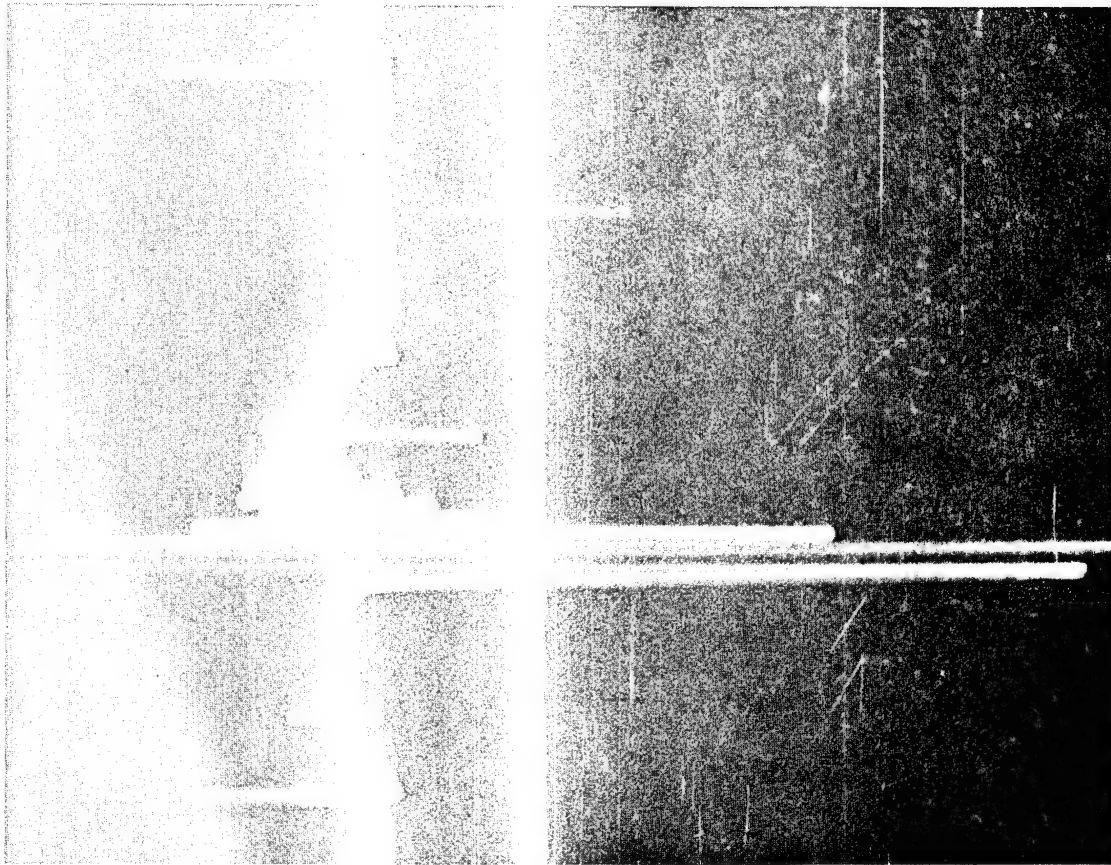
- (a) on magnetic tape of the audio output of a receiver tuned to the Lamplight 3440 km frequency,
- (b) on continuously moving film of the second detector output of the above,
- (c) on continuously moving film with the broad-band (0.5 - 50 kc) "Tweek" receiver.

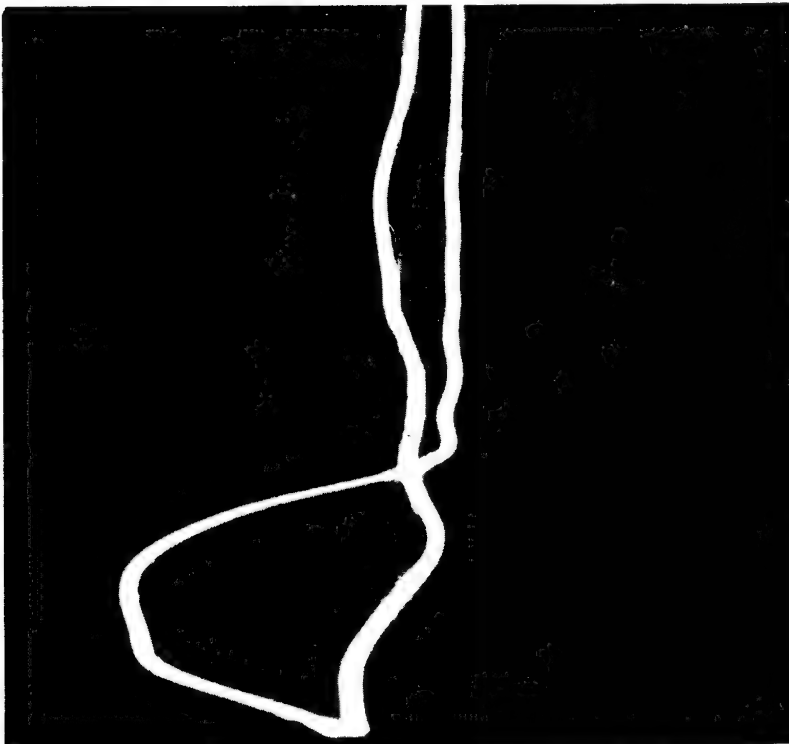
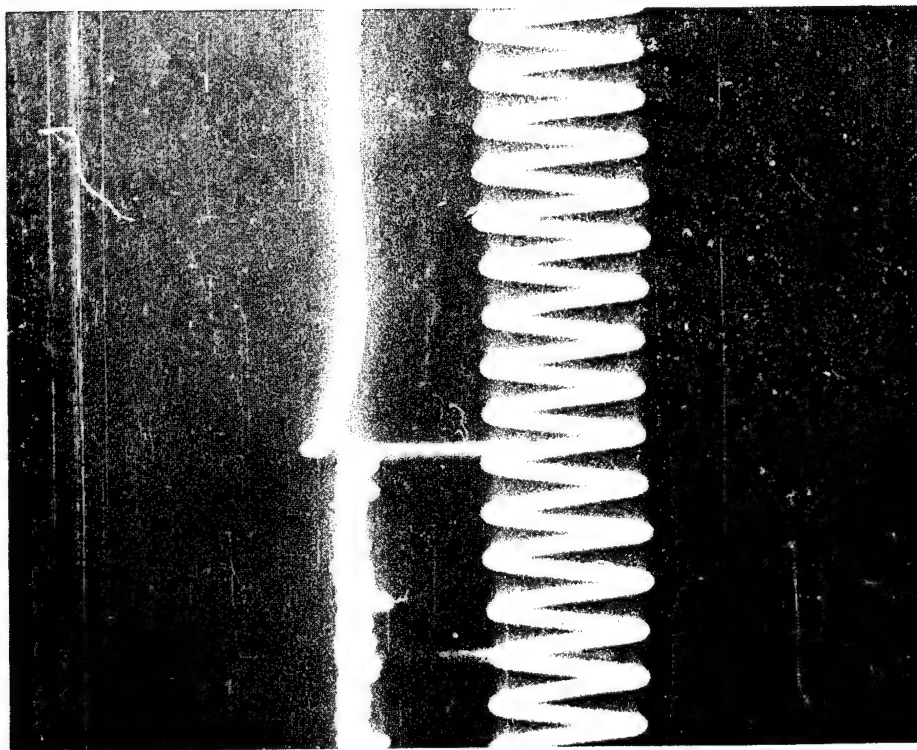
Pulses received from Shot 8 are shown in Figure 4.17.



Pulse beginning; 200 ms/cm; approximately 337 ms between pulses, corresponding to a difference in transmission distance of about 101 km. (Negative retouched.)

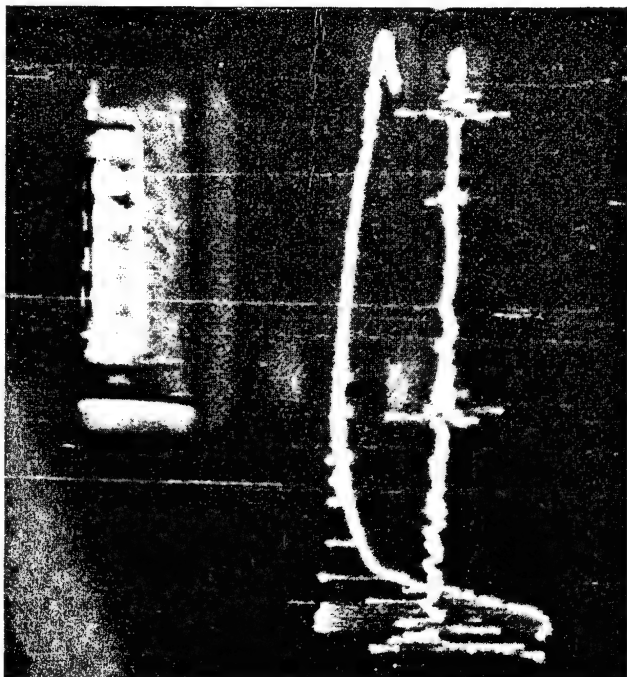
Fig. 4.15 Boulder, Colorado. Pulses on 9.10 mc. Shot 3, 22 April 1952. Note double pulse on second print due to reflection from different ionospheric layers. 7



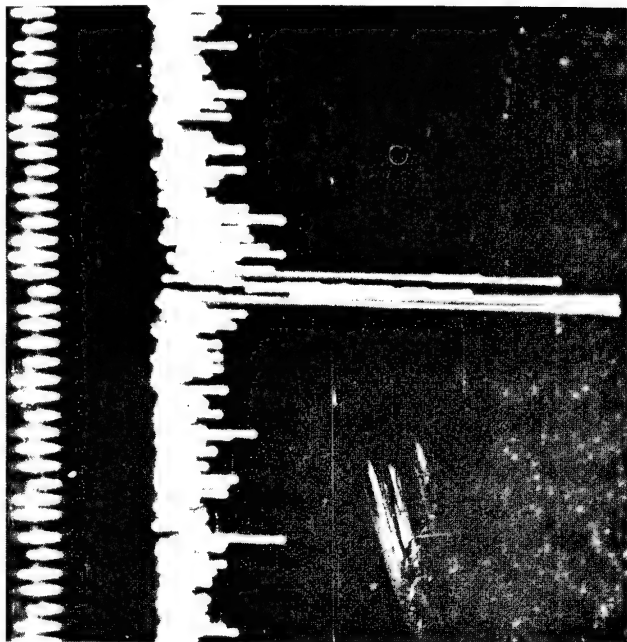


100 ms/cm

Fig. 4.16 Boulder, Colorado. Pulses on 5.06 mc. Shot 5, 7 May 1952. No double pulses, \angle which would indicate more than one reflection layer, are evident on second print.



Shot 7. "Tweek" receiver; total sweep time, about 6.8 mc.



Shot 8. 3.440 mc. This is a photograph of the original film recording of the second detector output of the SP-600 receiver.

Fig. 4.17 Stanford University, Typical Pulses \mathcal{Z}

At no time during the period approximately plus 3 minutes to plus 34 minutes after the bombs were exploded were any significant differences noted on the continuous C-3 vertical incidence ionospheric records. Zero times are given in Table 4.1.

4.2.3 Sterling, Virginia (3380 km)

Narrow band measurements were made at the Central Radio Propagation Laboratory station. The experiments did not produce any self-evident pulses, but after detonation times were known, it is believed that signals can be distinguished for Shots 4 and 8. It is significant that the noise level at Sterling was sufficient to cause the RBA and NBS-1 records to be used at much less than maximum rf gain, while at Boulder full rf settings could be used.

Zero times are given in Table 4.1. No corrections have been made for propagation times.

TABLE 4.1

Summary of Zero Times at Close-in and NBS Locations

Shot No. and Date	Close-in	Stanford Univ.	Boulder Colo.	Sterling Va.
3 22 Apr 52	Not operating.	Not operating.	Considered positive but no zero time - malfunction of timing equipment.	Nil.
4 1 May 52	1629:58.655Z	Not operating.	Considered positive; Lamplight interval 5.00 sec.	1629:58.67
5 7 May 52	1214:59.246Z	Interference.	Considered positive; Lamplight interval 5.039 sec.	Nil.
6 25 May 52	1159:59.774Z	1159:59.756Z	1159:59.757Z	Nil.
7 1 June 52	1154:59.818Z	1155:00.00Z	1154:59.822Z	Nil.
8 5 June 52	1155:00.326Z	1155:00.314Z	1155:00.312Z	1155:00.355

[REDACTED]

4.2.4 Maynard, Mass., Alamogordo, New Mexico, and Camp King, Germany

The very low frequency equipment (up to about 20 cps) at Maynard, Mass. and Alamogordo, New Mexico was in operation for Shots 2 through 8. Listening conditions varied from very quiet to very noisy, but in no case is there an observable signal within a few seconds of zero time. These experiments can be considered negative.

At Maynard, Mass. low frequency monitoring was at 50 kc and high frequencies at about 14 mc for Shots 2 through 8. Narrow band equipment was used. At 0.6 sec after Shot 8, a strong pulse was recorded on 14.6 mc, 12.6 mc and 50 kc. Signals at all other times did not correlate within a second of zero time, so this result probably is due to random noise.

Operational difficulties were encountered at Camp King, Germany. Some records were obtained for Shots 3 through 8, but all are considered negative.

4.2.5 Direction Finding with Sferics Equipment.

At least two of the four Air Weather Service stations shown on Figure 3.1 were operated for Shots 2 through 5. Through a misunderstanding, proper notification was not given for Shots 6 through 8. Runs were made at times instructed, which covered a period of 5 minutes before predicted shot time and up to 10 minutes after shot time.

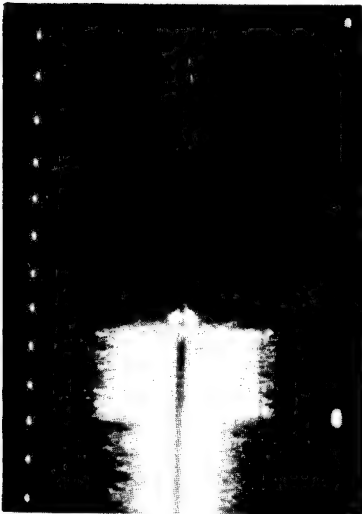
Results are summarized in Table 4.2, and the series of records for 7 May 1952 is presented in Figure 4.18.

4.2.5.1 System Errors

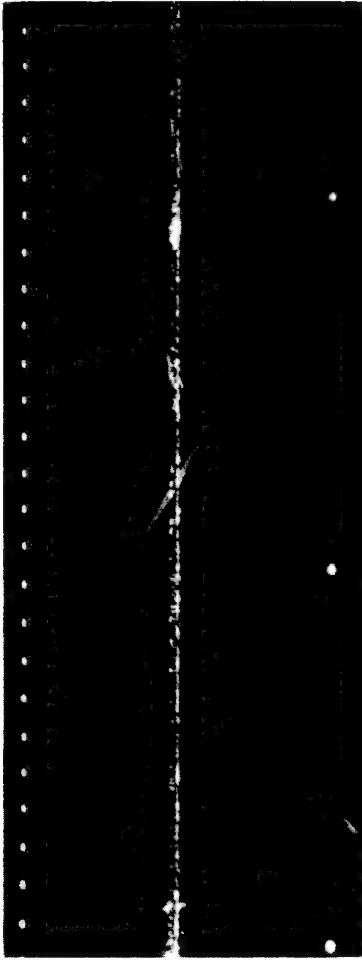
The equipment as presently used is subject to some errors, both mechanical and electronic. They can be summarized as follows:

(a) Timing errors. The timing drums, driven by a synchronous motor, have contact points which close micor-switches, thus flashing the neon timing lights. With use, the contacts sometimes get worn causing uneven time flashes and flashes of varying length. Because of these uncertainties, an operational tolerance of ± 0.05 second is allowed in flash synchronizations.

(b) Bearing errors. During a phase of the development of the Sferics program, consistent bearing errors were

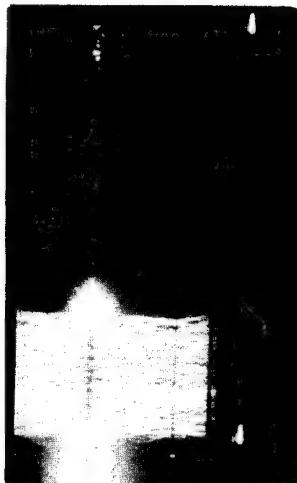


WWV Correlation

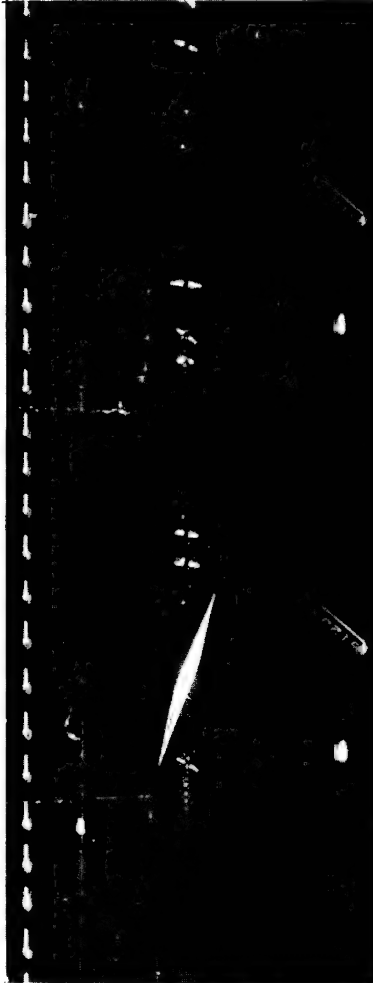


Flash-1214:59.25; azimuth 303°
(True time - 1214:59.25; true azimuth 305°)

RAMEY AIR FORCE BASE

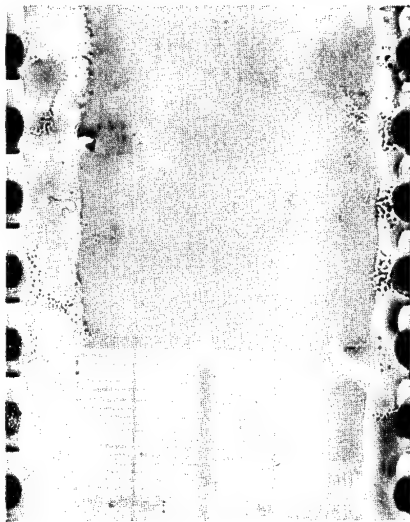


WWV Correlation

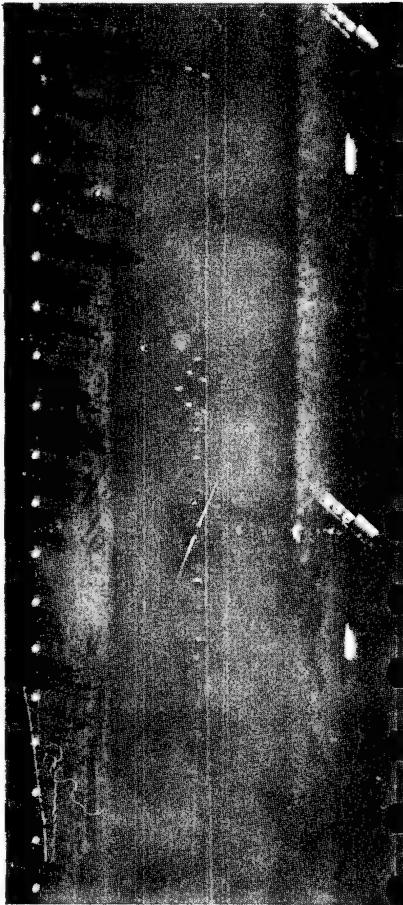


Flash - 1214:59.28; azimuth 289°
(True time - 1214:59.25; true azimuth 290°)

ROBINS AIR FORCE BASE



WWV Correlation



Flash - 1214:59.25; azimuth 292°
(True time - 1214:59.25; true azimuth 298°)
MACDILL AIR FORCE BASE

Enlargements of 35-mm film Sferics records for 7 May 1952. The marks at the top of each record are 0.1 sec marks; those at the bottom are 1.0 sec marks. A mechanical timer, pictures of which are seen adjacent to the second marks, numbers each second from the time the recording begins. A correction is applied, depending on accuracy of timing with WWV, as shown in the correlations above with each Sferics record.

Fig. 4.18 Sferics Records, 7 May 1952

TABLE 4.2

SUMMARY OF SPHERICS RESULTS

Station and true Azimuth to Test Site ($\pm 1^\circ$)	15 April 1952 1729:57.00*		22 April 1952 1730:10.02*		1 May 1952 1629:58.66**		7 May 1952 1214:59.25**	
	Azimuth and diff. from true Azimuth	Time and diff. from true Time	Azimuth and diff. from true Azimuth	Time and diff. from true Time	Azimuth and diff. from true Azimuth	Time and diff. from true Time	Azimuth and diff. from true Azimuth	Time and diff. from true Time
Robins AFB 290°	288° -2°	:56.54 -.46 sec	288° -2°	:09.82 -.20 sec	288° -2°	:58.70 +.04 sec	289° -1°	:59.28 +.03 sec
MacDill AFB 298°	296° -2°	:56.58 -.42 sec	293° -5°	:09.74 -.28 sec	***	:58.64 -.02 sec	292° -6°	:59.25 0.00 sec
Ramey AFB 305°	No test.		No test.		No test.		303° -2°	:59.25 0.00 sec
Kindley AFB 291°	No test.		296° +5°	:09.77 -.25 sec	No test.		No test.	

* EGG Zero Times

** To the nearest .01 sec.

*** WWV obscures the flashes, but there is a pip on the WWV frequency at time indicated.

[REDACTED]

noted for various stations when signals were received from certain quadrants. Further experimentation by Air Weather Service and the Signal Corps Engineering Laboratories showed clearly that there existed an error curve with maximums 180° apart. Experimentation is continuing but the largest error seems to be due to mis-tuning of the loop and amplifier, with subsidiary errors due to travel of the incoming wave over water and varying terrain and misorientation of the loops. At distances from the stations to the Nevada Proving Grounds, a bearing error of $\pm 3^\circ$ is not unreasonable.

Using the above criteria, from the 10 records taken, five fall within the above time limits of ± 0.05 second (Refer to Table 4.2). Azimuth can be determined from nine records, and six of them are within $\pm 3^\circ$ of the measured azimuth to the detonation location. There are only three records that fall within both time and azimuth error limits. It will be noted, however, that times for a given shot are quite consistent and that bearing errors from a given station all have the same sign. The sinusoidal error curve may account for some of the errors, a maximum being at 315° . However, the one record from Ramey, azimuth to site 305° , shows an error of -2° , -5° , and -6° .

4.2.5.2 Lightning Flashes Close to Zero Times.

An analysis was made of the number of flashes for 15 seconds on each side of zero time for the dates 22 April and 7 May, in order to determine thunderstorm activity. Figures 4.19, 4.20 and 4.21 for 7 May show that there was no thunderstorm activity from the direction of the test site. A similar plotting of the 22 April data shows limited thunderstorm activity within about $\pm 15^\circ$ of a line towards the site. An examination of all the records shows that, in general, at the times of the bomb tests, less than 5 per cent of the naturally occurring flashes had azimuths $\pm 3^\circ$ of true azimuth.

5.0 CONCLUSIONS

Although preparation for this series of tests was better than for BUSTER-JANGLE, the work performed must still be considered preliminary.

The results indicate that there is no doubt about the presence of electromagnetic disturbances at the time of an atomic explosion; these disturbances can be detected at rather large distances, although the certainty of detection at distances for explosions of the size detonated during TUMBLER-SNAPPER depends chiefly on the use of sites with low background and secondly the ability to distinguish the bomb electromagnetic pulses from all the other atmospheric static.

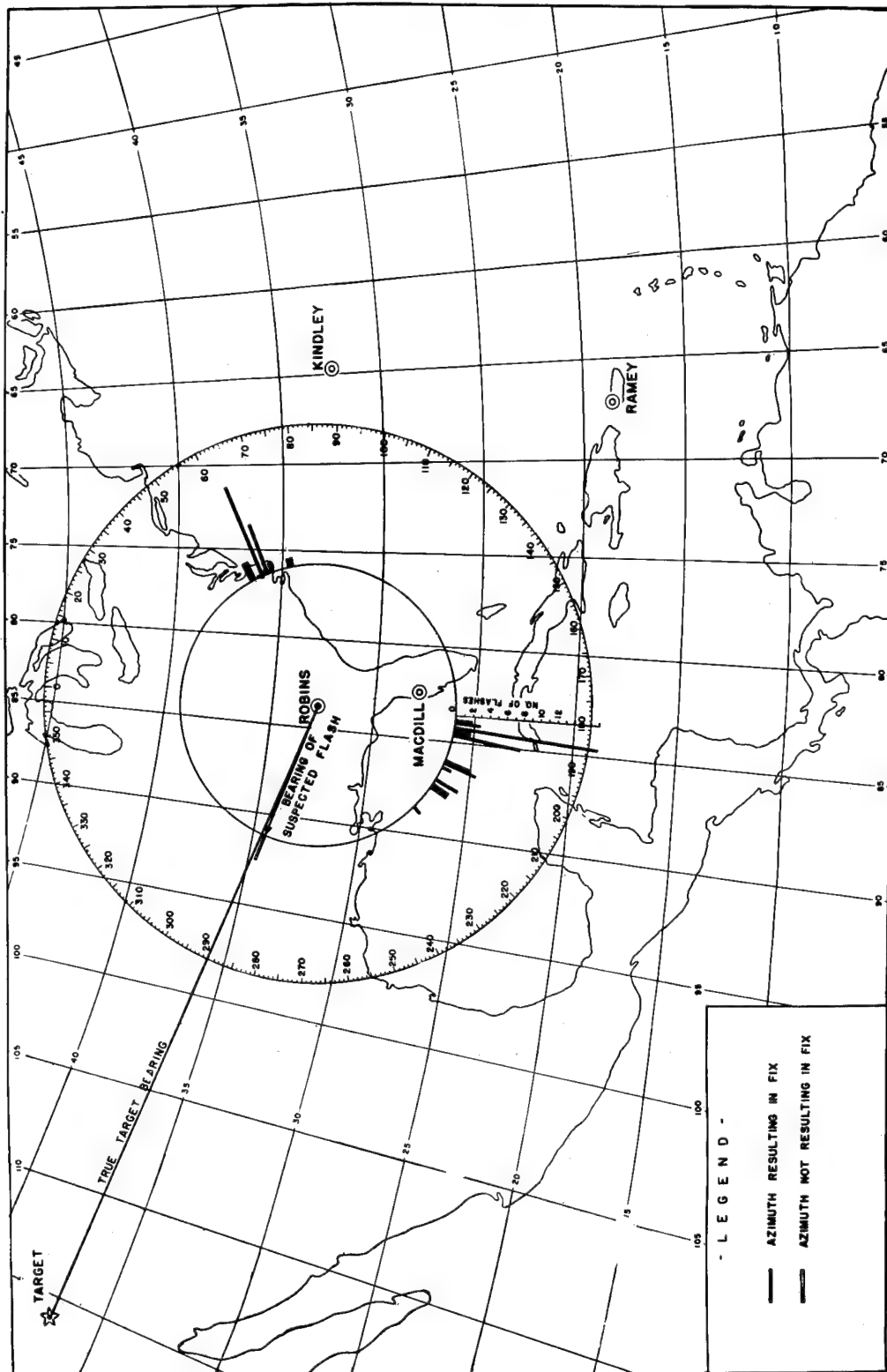


Fig. 4.19 Azimuth Frequency Rose for Robins (1214:45 to 1215:15 GMT, 7 May 1952)

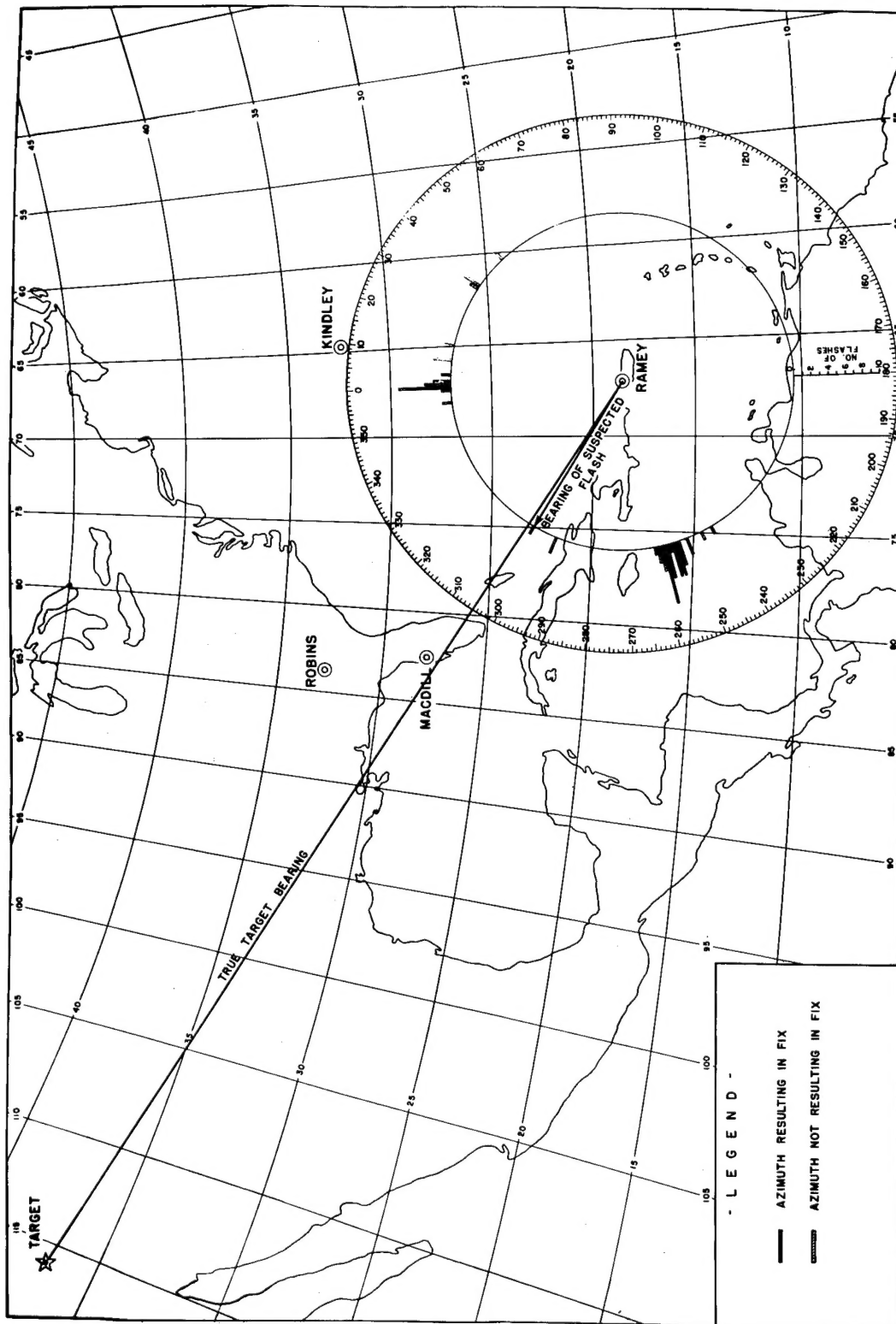


Fig. 4.21 Azimuth Frequency Rose for Ramey (1214:45 to 1215:15 GMT, 7 May 1952)

[REDACTED]

The results with standard direction-finding equipment appear promising, although it cannot be said, on the basis of the present report, that atomic bomb pulses were definitely received; this is primarily because of the errors in timing and azimuth. In addition, the Sferics stations were located at undesirable spots for location of atomic bomb detonations at such great distances to the west.

There was no indication of detection at extremely low frequencies at either White Sands or Boston. It is probable that the apparent lack of detection in the Boston area and Germany was because of high noise level and poor timing.

The close-in pulse measurements indicate tentatively that the greatest field strength lies in the kilocycle region. It was not possible to obtain reliable information on pulse character because of the inability of the equipment used to respond to the sharp pulses emanated.

The field strength measurements made close-in demonstrate that the explosion causes perturbations in the normal atmospheric electrical current system. These changes persist for several minutes, and where a portion of the cloud floats over the recording instruments, for several hours afterward.

6.0 RECOMMENDATIONS

Further work should emphasize the determination of true pulse character and its changes with atmospheric propagation. For eventual use of this phenomena for long range detection, the studies should be directed toward the relationship of pulse character with bomb characteristics, and means of discriminating between normal atmospherics and bomb pulses.


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